STRUCTURAL AND METAMORPHIC HISTORY
OF THE PACQUET HARBOUR - GRAND COVE AREA,
BURLINGTON PENINSULA, NEWFOUNDLAND

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STRUCTURAL AND METAMORPHIC HISTORY

OF THE PACQUET HARBOUR - GRAND COVE AREA, BURLINGTON PENINSULA, NFLD.

by Howard J. Coates

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Chapter I. INTRODUCTION

A. Location, Settlement and Accessibility.

The Pacquet Harbour - Grand Cove map area is located on the north shore of the Burlington Peninsula, northeast Newfoundland, approximately 15 miles due east of Baie Verte. The map area covers approximately 25 square miles encompased by geographic coordinates 49° 53' 50" and 49° 58' 40" north latitude and 55° 57' 00" west longitude.

The marginal parts of the area are easily accessible, the north-eastern part by small boat and the southern and western parts by the LaScie and Woodstock roads. The interior can be reached on foot from the roads. The only settlement is the village of Woodstock (pop. approx. 500) in the north-western corner of the area. The main means of livelihood for its inhabitants are a local saw mill operation and the inshore fishery.

B. Physiography and Vegetation.

This region shows undulating terrain with a maximum elevation of approximately 750 feet above sea level. About 90% of the coastal section shows bedrock exposed in good cliff sections.

A thin cover of overburden masks a substantial part of the interior, especially the schistose metavolcanics of the Pacquet Harbour Group. Because they are more siliceous, the quartz felspar porphyry and the acid volcanic rocks are usually well exposed inland. The drift covered areas underlain by the Pacquet Harbour Group support spruce and fir timber forests.

The areas underlain by the siliceous rocks support only scrub spruce and small timber stands.

C. General Geology:

The Appalachians in north-eastern Newfoundland can be divided into three distinct geological provinces; namely, the western platform, the eastern platform and a central palezoic mobile belt (Williams, 1964) (Fig. I-1). The mobile belt consists almost entirely of Ordovician and Silurian rocks which are regionally deformed, metamorphosed and intruded by a variety of plutonic rocks. The rocks are not highly metamorphosed except in narrow marginal belts, known as the lower unit of the Gander Lake Group in the east and as the Fleur de Lys Supergroup in the west. These rocks have a much more complex structural and metamorphic history than the Ordovician and Silurian rocks and are believed by most workers to be older.

The Burlington Peninsula, located on the western side of the mobile belt, (Fig. I-2) is underlain by a variety of volcanic, plutonic and sedimentary rocks which have undergone varying degrees of metamorphism and deformation. The oldest rocks are psammitic and pelitic schists, and minor meta-conglomerate, amphibolite and marble which have undergone at least three penetrative deformations and several metamorphic events. These rocks occupy a 70 mile long belt which extends southwestward from Partridge Point to the bottom of White Bay. Kennedy (in press) has separated the rocks of the northwestern part of the peninsula into

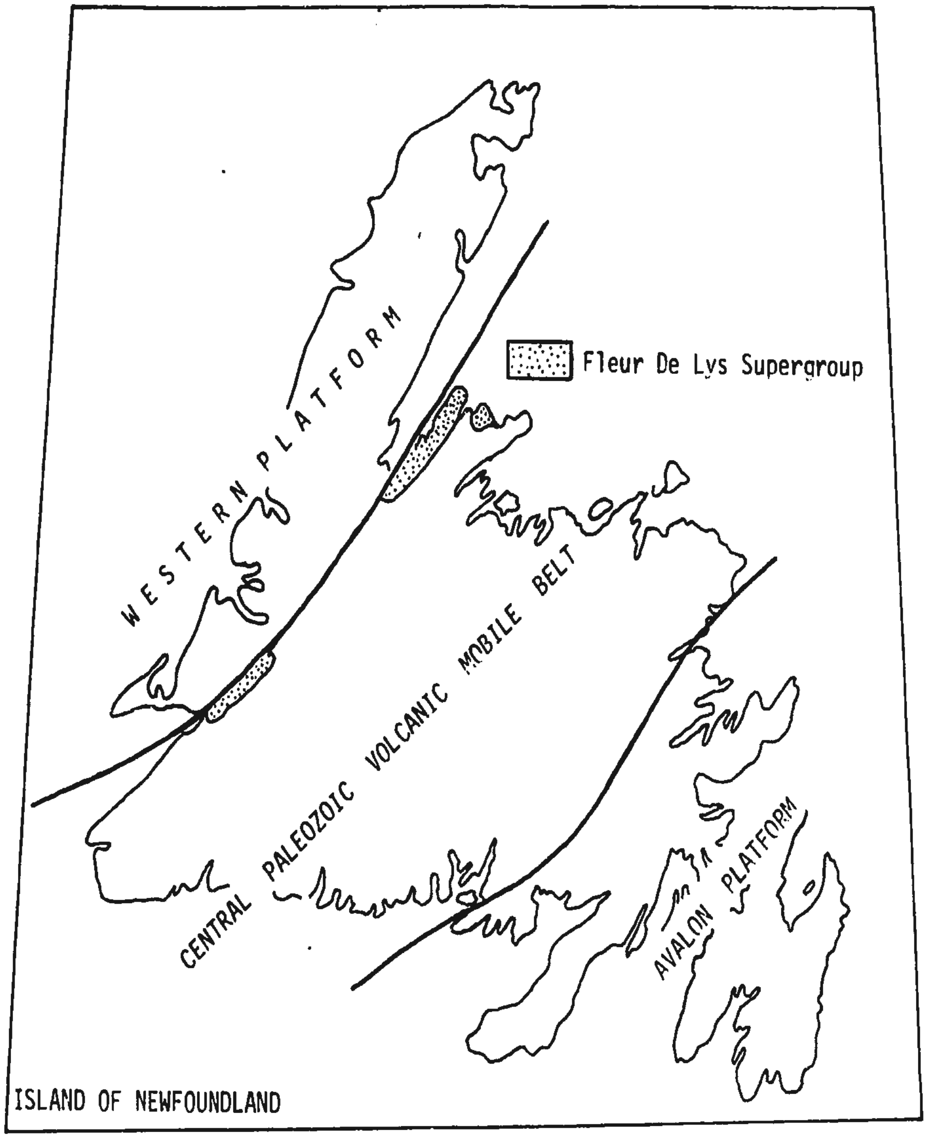


Figure 1-1: Distribution of the Fleur De Lys Supergroup rocks with respect to major Paleozoic tectonic elements of Newfoundland

a number of sequences of formations separated by tectonic slides. East of Baie Verte another group of similar psammitic shists known as the Ming's Bight Group are apparently conformably overlain by a group of basic shists and lineated amphibolites known as the Pacquet Harbour Group. These rocks are collectively known as the Fleur de Lys Supergroup.

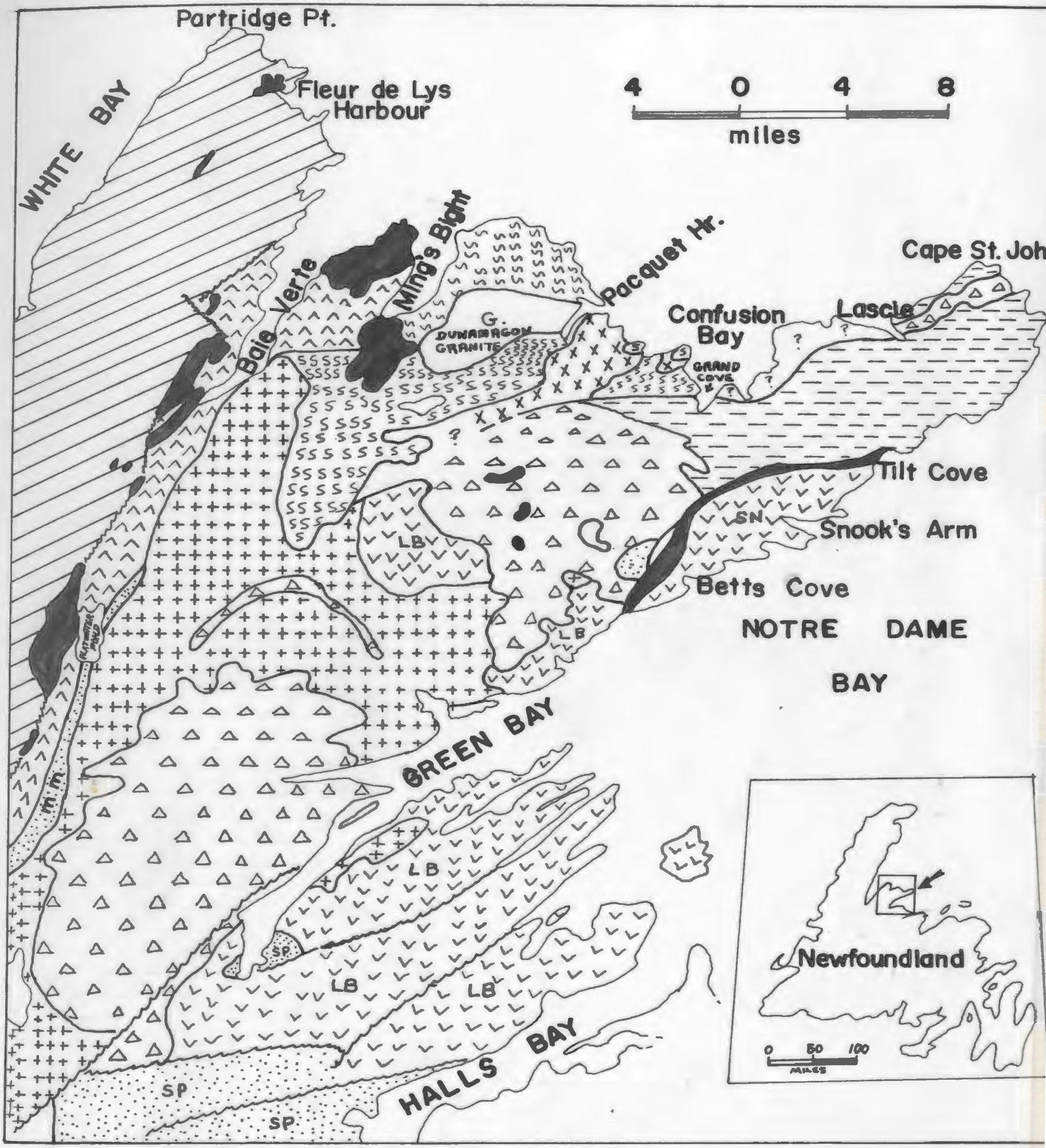


Figure I - 2. Burlington Peninsula, Newfoundland; modified after Neale and Kennedy (1967).

Key to Figure I - 2

G. Devonian granitic rocks.

Silurian

Acid and basic volcanic, clastic sediments.
SP - Springdale Group.
MM - Mic Mac Sequence.

Silurian (?) or older

Quartz-felspar porphyry and acid pyroclastic rocks.

Cape St. John Group, acid & basic volcanics, clastic sediments.

Ordovician (?) or later

Ultrabasic and related rocks.

Baie Verte Group: basic lavas and minor sediments.

Ordovician

Pillow lavas:
LB - Lush's Bight Group.
SN - Snook's Arm Group.

Pre-Ordovician

Burlington Granodiorite.

Cape Brule' Porphyry.

Pacquet Harbour Group.

Ming's Bight Group.

Fleur de Lys Group.

Ordovician basic volcanic rocks, known as the Snook's Arm and Lush's Bight groups, occur on the eastern side of Burlington Peninsula. Correlated with these, on the basis of lithology, is a linear belt of rocks, the Baie Verte Group, which is in apparent fault contact with the eastern side of the main Fleur de Lys belt. If the above interpretations are valid a relative age of pre-Lower Ordovician can be assigned to the Fleur de Lys Supergroup.

The best evidence for the age of the Fleur de Lys Supergroup comes from the Klippe of Western Newfoundland. Fleur de Lys type rocks have been found in the eastern part of the Hare Bay Klippe. These rocks contain at least two deformations not found in the melange zones and are possibly correlatable with D_1 and D_2 of the Fleur de Lys (W.R. Smyth; personal communication). The age of emplacement of these klippe rocks have been dated in the Humber Arm region of Newfoundland as Middle Ordovician (Rodgers & Neale - 1963, Stevens - 1966).

The north-eastern part of the Burlington Peninsula is underlain by a complex volcanic assemblage known as the Cape St. John Group. A Silurian age (Neale & Nash - 1963) has been assigned to it on the basis of lithological similarities between it and the dated Botwood and Springdale Groups, which are typical of the Silurian of the northwestern mobile belt.

Another narrow belt of similar rocks near Flatwater Pond known as the Mic Mac Sequence uncomformbaly overlies the Burlington Granodiorite and lies in apparent fault contact with the Baie Verte Group. This has been tentatively correlated with the Cape St. John Group. A Rb/Sr age date of 393 m.y. has been obtained from these rocks. (GSC paper 67-17)

Intrusive into the above rocks are a variety of plutonic rocks ranging in composition from ultrabasic to granitic and in age from Ordovician and older to Devonian. There are three main areas of ultrabasic rock on the Burlington Peninsula; a linear belt which extends southwards from Baie Verte situated at or near the Fleur de Lys - Baie Verte groups contact, a curved belt on the eastern side of the peninsula at or near the junction between the Cape St. John and Snook's Arm Groups, and two bodies near the Ming's Bight - Baie Verte Group contact. These are considered to be of Ordovician age (Neale & Nash - 1963). Other acid intrusive rocks range in age from Silurian (?) or older to dated Devonian.

Two groups of metamorphic rocks can be separated with respect to the present map-area. The oldest and most complexly deformed is the Fleur de Lys - Pacquet Harbour Group. The other is a less complexly deformed lower grade assembly known as the Cape St. John Group. Between the two is an acid volcanic sequence known as the Grand Cove Group, which was originally mapped as part of the Cape St. John Group but has since been the subject of controversy (Church - 1967, 1969). Part of the present study was to determine its relationship to the Fleur de Lys Supergroup.

A quartz-felspar porphyry intrudes the Cape St. John Group and was originally believed to be Silurian in age. Relationships noted within the present area show that the porphyry is at least in part intrusive into the Pacquet Harbour Group before its first deformation. This is believed to have been emplaced before the Cape St. John Group was formed.

D. Previous Work.

The earliest geological map of Newfoundland published by Alexander Murray in 1873 shows the Burlington Peninsula underlain largely by PreCambrian "Laurentian" gniesses. These correspond roughly to the granitic rocks of the peninsula. All other rocks he called "Lauzon".

J.P. Howley's map published in 1907 shows the peninsula as a group of "serpentines, diorites and dolerites", with a few elongate granitic bodies.

Fuller (1941) in a study of the Fleur de Lys Area described the rocks as "metamorphic", "derived from sedimentary rocks which were mainly shaly sandstones", " believed to be PreCambrian in age". A broad syncline and anticline affecting the Fleur de Lys area was the only major structure described but several localities showed "extreme contortions", which were attributed to "structural weakness".

Watson (1947) mapped an area between Ming's Bight and Baie Verte.

In his report he described a group of gniesses called the Rattling Brook Group which he correlated with the gniesses of the Fleur de Lys area mapped by Fuller. He considered the possibility that they might be Paleozoic rocks but nevertheless referred to them as Pre-Cambrian.

Also in his report he described a group of schistose volcanic rocks which he referred to as the Baie Verte Formation. He subdivided the formation into greenstones or chlorite schists and amphibolites. The amphibolites were believed to be greenschists upgraded by contact metamorphism related to granitic intrusion.

Watson also mapped a unit of psammitic schists on the east shore of Ming's Bight which he referred to as the Ming's Bight Formation. He interpreted these psammites as, " part of the Ordovician (?) section underlying the Baie Verte Formation, which has been silicified and otherwise metamorphosed by a large granite intrusive known to occur a short distance east of Ming's Bight."

Betz (1948) mapped the western shore of Burlington Peninsula and called the schists and gniesses he observed the White Bay Group. He inferred that these were continuous with the Fleur de Lys area gniesses but did not make any specific correlation.

The first comprehensive work on the Burlington Peninsula was published by Baird (1951). He proposed the name Fleur de Lys Group for the belt of gniesses and schists described by Fuller (1941), called the Rattling Brook Group by Watson (1947) and the White Bay Group by Betz (1948). He interpreted the structure of the belt as a broad anticline.

The Ming's Bight Formation was raised to Group status and tentatively correlated on the basis of lithology with the Fleur de Lys Group.

The Baie Verte Formation was renamed Baie Verte Group and extended eastward to include amphibolites near Confusion Bay and greenschists at Cape St. John.

Baird also proposed the name Cape St. John Group for the volcanic assemblage underlying the northeastern part of the peninsula. He called them Ordovician because of similarities with the Ordovician rocks of Notre Dame Bay.

He grouped all the intrusive rocks of the peninsula into one complex of Devonian age. This included the Burlington Granodiorite, the Dunamagon Granite and the Cape Brule' Porphyry. The Cape Brule' Porphyry extended from the Cape Brule' headland southward to the latitude of Nipper's Harbour.

Neale (1958 a) retained Baird's nomenclature but modified and subdivided many of the map-units. The amphibolites near Pacquet Harbour, previously called Baie Verte were put into the Cape St. John Group together with a belt of silicic volcanic rocks which were originally mapped as part of the Cape Brule' Porphyry. He correlated the Cape St. John Group with the Springdale Group which was then considered to be Devonian in age.

An apparently conformable contact was noted between the Ming's Bight Group and the Baie Verte Group at Pelee' Point near Pacquet Harbour.

Neale and Nash (1963) state the presence of Silurian (?) rocks, the Mic Mac Sequence, overlying the Burlington Granodiorite in spectacular unconformity and in faulted contact with the Baie Verte Group.

W.R. Church began a continuing study of the Burlington Peninsula in 1963. His results were made public by oral reports which were summarized by a series of abstracts.

Church (1965) attempted to unravel the structural history of the peninsula. He stated that the Fleur de Lys Group was in "structural continuity", with the Baie Verte Group which in turn was "conformably overlain", by the Cape St. John Group. He grouped them all into one "structural unit", containing "three comparable phases of tectonic deformation."

Church (1966) modified his ideas stating that the Baie Verte Group was unconformably overlying the Fleur de Lys Group and the Burlington

Granodiorite. He correlated the Baie Verte Group with the lower Ordovician Snook's Arm Group on the basis of lithologic similarities and assigned a relative age of Pre lower Ordovician to the Fleur de Lys rocks. The Cape St. John Group was considered to be Silurian (?) in age.

Church (1967, 1969) collectively referred to all the high grade metamorphic rocks of Burlington Peninsula as the Fleur de Lys Supergroup. The eastern division of the Supergroup consisted of the Ming's Bight Group, the Pacquet Harbour Group (formerly the amphibolites of the Baie Verte Group) and the Grand Cove Group (formerly the Cape St. John Group). He considered these groups as a conformable sequence.

Neale and Kennedy (1967) discussed the general geology and outlined some specific problems of Burlington Peninsula. They agreed with Church (1967) who interpreted the Ming's Bight and Pacquet Harbour Group as belonging to the Fleur de Lys Supergroup and supported his interpretation with a comparable intergroup study of structural and metamorphic history. A narrow belt stretching from Grand Cove to LaScie (part of Church's Grand Cove Group) was reinterpreted as a metamorphosed facies of the Cape St. John Group because of contrast in structural and metamorphic styles between the two.

E. Present Investigation.

The present study stems from the controversial opinions on the Pacquet Harbour Group - Grand Cove Group relationships. In the absence of fossils it was deemed necessary to make a detailed structural, metamorphic and lithologic comparison between the Pacquet Harbour Group and the Grand Cove Group. It may then be possible to draw analogies with the Cape St. John and Fleur de Lys groups as described by Neale and Kennedy (1967), Kennedy (in press) and Church (1969).

Kennedy (personal communication) outlined the possibility of there being two spatially related quartz - felspar porphyrys one related to the Fleur de Lys and the other to the Cape St. John. Part of the thesis project was to explore this possibility.

The study was begun with detailed lithological and structural mapping of the excellently exposed coastal section between Woodstock and Grand Cove. This information was augmented by good road and stream sections. A few cross country traverses were made but were found to be of little use in determining inter group relationships. Laboratory studies included systematic petrographic and textural studies of approximately 70 thin sections.

Chapter II. Lithological Description

The Pacquet Harbour - Grand Cove area is underlain by two distinct groups of meta-volcanic and intrusive rocks. One of these, consisting of the Pacquet Harbour Group and Cape Brule' Porphyry is of pre-Ordovician age. The other consisting of the Grand Cove Sequence and what is termed the Cape St. John Porphyry has been considered to be Silurian (?) by some workers (Neale and Nash 1958, Neale and Kennedy 1967) and pre-Ordovician by others (Church 1967, 1969).

A. Pre-Ordovician:

(a) Pacquet Harbour Group: The Pacquet Harbour Group consists chiefly of an assemblage of basic volcanic rocks with intercalated semi-pelitic schists and minor meta-conglomerate. Intrusive into these rocks are a few meta-gabbroic bodies of irregular outline and limited areal extent. These rocks have been subjected to intense polyphase deformation and metamorphism and are now highly strained rocks belonging to the upper greenschist or lower amphibolite facies of regional matamorphism.

The group can be divided into two different outcrop belts within the present thesis area (see map). The western belt extends from Pacquet Harbour south-westward to the junction of the Woodstock and LaScie roads. It consists mainly of lineated amphibolites which show relic igneous features such as amygdules, tuffaceous bands and possible phenocrysts. Deformed pillows were noted in the Pacquet Harbour Group a few miles west of the area on the LaScie road. Intercalated with the

SILURIAN (?) OR OLDER	CAPE ST. JOHN PORPHYRY		(i) Quartz-felspar porphyry
	INTRUSIVE OR UNCONFORMABLE CONTACT		
	GRAND COVE SEQUENCE	(not in stratigraphic order)	(i) Potash rhyolite
			(ii) Coarse grained acid pyroclastic rocks.
			(iii) Fine grained acid tuff.
UNCONFORMITY OR TECTONIC JUNCTION			
PRE-MIDDLE ORDOVICIAN	CAPE BRULE PORPHYRY		(i) Schistose quartz-felspar porphyry
	INTRUSIVE CONTACT		
	PACQUET HARBOUR GROUP	(not in stratigraphic order)	(i) Lineated hornblende amphibolite
			(ii) Semi-pelitic schist
			(iii) Meta-diorite
			(iv) Porphyroblastic hornblende amphibolite
			(v) Quartz-biotite-felspar-magnetite schist.
			(vi) Deformed agglomerate

Figure II-1. Table of Formations

volcanic amphibolites are bands of thinly bedded semi-pelitic schist. Presumably intrusive into the assemblage are irregular bounded bodies of medium to coarse grained meta gabbro.

The eastern belt of the Pacquet Harbour Group extends eastward from Gooseberry Cove to Cape Cagnet and southward to the latitude of Grand Cove. Unlike the west belt, these rocks contain few recognizable primary features and seem to have undergone a stronger degree of recrystallization. The major units of this belt are intercalated porphyroblastic hornblende amphibolite and quartz-biotite-magnetite-felspar schist and minor amounts of highly recrystallized meta-conglomerate. A few small meta-diorite bodies intrude the assemblage.

The rocks of the east and west belts can be correlated on the basis of their relationships to major structures, general lithology, textural similarities and metamorphic grade (Fig. II-2). This will be discussed in detail in later sections of this thesis.

Rock Types of the Pacquet Harbour Group:

(i) Lineated hornblende amphibolite: Rocks of this subdivision are basic volcanic flows and banded tuffs which have undergone a complex deformational history. Most primary features of the rocks were obliterated by the tectonism. A weli developed L-S fabric (L>S) (Flinn (1965 b)) is characteristic of the unit. This fabric is shown by an allignment of acicular hornblende crystals which are usually

PACQUET HARBOUR GROUP		
	East Belt	West Belt
LITHOLOGIC UNITS (not in stratigraphic order)	Porphyroblastic hornblende amphibolite	Lineated hornblende amphibolite
	Quartz-biotite-felspar-magnetite schist	Semi-pelitic schist
	Meta-diorite	Meta-diorite
	Deformed agglomerate	
STRUCTURAL AND TEXTURAL FEATURES	L_1 (observed)	L_1 (common)
	F_2, S_2 (common)	F_2, S_2 (common)
	F_3 (common)	F_3 (common)
METAMORPHIC FEATURES	Late hornblende porphyroblasts (very common)	Late hornblende porphyroblasts (observed)
	Garnets (rare) ; Epidote-plagioclase replacements of garnet (common)	Garnet porphyroblasts (common)

Figure II-2. Correlative analysis of the east and west belts of the Pacquet Harbour Group.

from 1 to 3 milimeters in length. A few larger randomly oriented amphiboles were noted. Modal percentage of hornblende ranges from 35 to 70 in the several sections examined.

Other mineral constituents of the amphibolites are plagioclase and quartz with minor biotite, epidote, garnet, magnetite and chlorite. The percentages of quartz and plagioclase (albite) are also variable ranging from 2 to 30% for quartz and from 10 to 45% for albite. Twinning is rare in the albite and both quartz and felspar show a well-developed polygonal fabric.

(ii) Semi-Pelitic Schist: Intercalated with the lineated amphibolites of the west belt of the Pacquet Harbour Group are thin layers of semi-pelitic schist. The rock is usually very fine grained and thinly banded. It is composed of about 30% quartz, 45% epidote, 25% hornblende and minor amounts of biotite. The presence of hornblende indicates a possible derivation of the sediments from the basic volcanics of the Pacquet Harbour Group. There is a possibility that some of the outcrops mapped as semi-pelite are in fact more siliceous banded tuffs.

(iii) Meta-Diorite: This is a medium to coarse grained rock consisting of 1 to 3% quartz, 40% plagioclase (An 35), 5% orthoclase, 50% hornblende, 5% magnetite and minor biotite. The plagioclase, unlike that of most other units in the Pacquet Harbour Group, occurs in large twinned crystals which may be phenocrysts. Some of the honrblende crystals define a weak schistosity.

It occurs in sill-like bodies and irregular stocks intrusive into the volcanic rocks of the Pacquet Harbour Group. The actual contact between a meta-diorite stock and the lineated amphibolite, observed in one locality on the Woodstock road, was found to be irregular and discordant with the bedding.

(iv) Porphyroblastic Hornblende Amphibolite: This is the dominant rock type in the east belt of the Pacquet Harbour Group. Its main mineral constituents are hornblende and albite with usually minor amounts of quartz, biotite, epidote, chlorite and magnetite. The hornblende occurs as large elongate (2 mm to 2 cm) randomly oriented porphyroblasts which contain included remnants of previously existing fabrics. Hornblende percentages range from 25 to 75% of the whole rock. The remaining minerals constitute a fine to medium grained almost equigranular matrix in which the porphyroblasts grew. Xenoblastic albite is the main constituent of the groundmass. The other constituents are not always present.

These rocks often exhibit well developed banding shown usually by the abundance of hornblende porphyroblasts. The origin of this banding is uncertain and could be either recrystallized primary compositional banding in sediments or volcanics, or metamorphic segregational banding, or a combination of both.

Spherical felspar-epidote bodies ranging from 2 to 10 mm in diameter are quite common in this unit. Some have vague dodecahedral outline suggesting that they might be replacements of garnet.

(v) Quartz-Biotite-Magnetite-Felspar Schist: This unit occurs interlayered with the porphyroblastic amphibolite. The layers vary from a few inches to hundreds of feet in thickness. Lithological boundaries are almost invariably gradational. The unit is a light grey fine to medium grained schistose rock consisting mainly of quartz, felspar, biotite, and magnetite with varing amounts of muscovite, calcite, epidote, hornblende and garnet. Felspar and biotite are the chief mineral constituents each having modal percentages between 15 and 35. Quartz usually comprises about 15% of the rock. Opaque minerals, usually magnetite, range from 10 to 30%. Calcite, although usually present in the order of 0.1% to 5%, in one section makes up 20% of the rock. Concentrations of muscovite and also epidote similar to that of calcite were found in other sections. Garnet and hornblende porphyroblasts were only rarely found. Epidote-felspar segregations similar to those described in (iv) are common in this unit.

(vi) Deformed agglomerate: This unit was found as a narrow belt near the top of Grand Cove in Confusion Bay. It consists of elongate flattened sub-angular lithic fragments in a foliated quartz-felspar-biotite matrix. The fragments vary in size from small pebbles to large cobbles and are of several different rock types the most common of which is a sugary textured felspar-epidote rock containing minor biotite. Next in order of abundance are irregular shaped basic to intermediate fragments. A few pinkish brown siliceous fragments were observed. Almost pure epidote fragments were seen locally.

The exact origin of this unit is not certain but since it occurs in an environment which contains tuffs, pillows and possibly other volcanically derived material the term aggolomerate is used although the possibility of it being of true sedimentary origin should not be overlooked.

(b) Cape Brule' Porphyry: Intrusive into rocks of the Pacquet Harbour Group is a body of coarse quartz-felspar porphyry known as the Cape Brule' Porphyry. This body underlies most of the western half of the map area extending southwesterly from the vicinity of Cape Brule' and Gooseberry Cove into the interior of the area. The porphyry has undergone a polyphase deformation history and shows the same structural and metamorphic phenomena as the Pacquet Harbour Group as far as composition, competence and planar anisotropy permits.

The rock consists of large (4 - 8 mm) phenocrysts of quartz, orthoclase and plagioclase (An. 4) in a fine to medium grained quartz-felspar-biotite groundmass containing accessory magnetite, muscovite, epidote and chlorite. Quartz and felspar phenocrysts exhibit sutured and embayed grain boundaries while the same minerals in the groundmass have a polygonal fabric developed thus indicating textural equilibrium. These metamorphic effects virtually destroy the primary igneous features. The platy minerals, usually biotite, have a well developed preferred orientation and give rise to augen structures around the phenocrysts.

The volume percentage of phenocrysts in the unit was found from ~~rough~~

rough modal analyses and field observations to be quite variable ranging from about 25% to about 60%. The different phenocryst minerals were also found to be variable, with quartz ranging from 35% to 65%, plagioclase from 5 to 30% and orthoclase from 25 to 60% of the total phenocryst content. The percentages of the various minerals in the groundmass were also found to be quite variable with quartz ranging from 25 to 40%, felspar from 10 to 45% and biotite from 10 to 30%. Accessory minerals, when present, rarely exceed 5% of the groundmass.

Deformed xenoliths and inclusions are common in the Cape Brule' Porphyry (Plate II-1a and 1b), and vary greatly in size and composition. The most common of these are light grey banded semi-pelitic schist xenoliths of variable size which generally contain interbedded psammitic schist. Next in order of abundance are hornblende-biotite-felspar schist or amphibolite xenoliths, some of which contain a hornblende lineation comparable to that found in the Pacquet Harbour Group. Small inclusions of almost pure biotite schist are common in the porphyry. Several other types of xenoliths were found in various parts of the Cape Brule' Porphyry. In all cases schistosity in the xenoliths is concordant with that of the host rock. G.L. Cockburn (personal communication) directed the writer to garnetiferous semi-pelitic schist xenoliths on the LaScie road near Southwest Brook. Several actinolite schist inclusions were found along the coastal section and at one location on the west side of Cape Canis several well defined xenoliths of very coarse grained quartz-felspar porphyry were observed. The source of all except the last mentioned type of xenolith is believed to be the Pacquet Harbour Group. The porphyry

Plate II - 1a - Stretched xenoliths in the Cape Brule' Porphryry: Cape Brule'.

Plate II - 1b - Stretched xenoliths of coarse grained quartz-felspar porphyry in medium grained quartz-felspar porphryry: Cape Canis xenoliths in all probability orginated from within the main porphyry body during its emplacement. Banding parallel to the plane of flattening of the xenoliths is widespread in the Cape Brule' Porphyry. The bands are elongate wispy lenticles of alternating light and dark material. The origin of the banding is uncertain and could be either primary or metamorphic

Since the Cape Brule' Porphyry contains inclusions and xenoliths of semi-pelite and amphibolite and since the Pacquet Harbour Group is cut by a few sill-like bodies of schistose quartz-felspar porphyry it is reasonable to assume an early intrusive interrelationship between them. However, the actual junction, observed in several places, shows no evidence of this. A sharp, locally straight, contact with either highly schistose or mylonitic zones was typical of all observed localities. It must therefore be concluded that there was movement along the contact at some time after intrusion during one or more of the periods of tectonic activity.

(c) Lamprophyre Dykes: Several 2 to 4 feet wide biotite lamprophyre dykes were found to intrude the Cape Brule' Porphyry. These dykes which are now strongly foliated biotite-felspar-calcite schists could commonly be followed up to 1000 feet. All primary features of the quartz-felspar porphyry, such as xenoliths and inclusions, are cut by the dykes and here and there tiny fingers of dyke rock extend into the porphyry. (Plate II-2)

The chief mineral constituent of the dykes is biotite which makes

Plate II - 2 . Lamprophyre dyke cutting the Cape Brule' Porphyry. It is parallel to and contains the first schistosity of the Pacquet Harbour Group and Cape Brule' Porphyry.

up about 45% of the rock. Felspar has a modal percentage of approximately 30% and quartz is present only in minor amounts. The rock contains approximately 20% calcite.

The dykes have the same structural-metamorphic history as the rocks they intrude.

B. Silurian (?) or Older:

(a) Grand Cove Sequence: The Grand Cove Sequence is an elongate belt of acid to intermediate flow and pyroclastic rocks having a less complex structural history and lower grade metamorphism than the pre-Lower Ordovician rocks of section A. The belt stretches eastward from Grand Cove to the south central part of the area where it comes in contact with the Cape Brule' Porphyry.

The belt has been divided into three units. The first belt is located immediately south of Grand Cove and has an outcrop width of approximately three-quarters of a mile within the map-area. Its lithology varies systematically from porphyritic rhyolite to massive aphanitic rhyolite. North of this belt along the shore of Grand Cove is a unit consisting of medium to coarse grained acid pyroclastic rocks with substantial amounts of intercalated volcanic pebble conglomerate. At the junction between the Pacquet Harbour Group and the Grand Cove Sequence there is a thin unit of fine to medium grained intermediate pyroclastic rock.

(i) Porphyritic to massive aphanitic potash rhyolite: This unit consists of subhedral phenocrysts of andesine (An 34) and orthoclase and a few rounded quartz phenocrysts in a pinkish brown siliceous aphanitic groundmass. The percentage of phenocrysts was found by field and laboratory observation to be usually small ranging in the order of 0.1 to 10%. The groundmass was found by sodium cobaltinitrite staining to be rich in potash and thus probably in K-felspar. The main mafic mineral in the groundmass is biotite which made up 5 to 10% of the rock. Epidote occurs as tiny poikiloblastic inclusions in the phenocrysts and as tiny grains in the groundmass. Phenocrysts are usually not recrystallized. Biotite shows only a weak schistosity.

(ii) Acid Pyroclastic Rocks: This unit consists of medium to coarse grained acid rocks which vary from crystal and lithic tuffs to coarse volcanic agglomerate. The tuffs consist of subhedral and anhedral plagioclase (An 36) and quartz together with quartzo-felspathic lithic fragments in a quartz, felspar, muscovite matrix containing minor calcite and epidote. The lithic fragments are invariably acidic in composition and range in size from a few millimeters in the tuffs and up to 25 centimeters in diameter in the agglomerates.

In general the unit is a complex intermixture of medium and coarse grained tuff, and agglomerate layers of variable thickness. The detailed stratigraphy is complicated by deformation which produced recumbent folding and a penetrative schistosity as well as abundant later small faults.

(iii) Fine Grained Acid Tuff: This unit has limited extent and was seen only as two narrow bands in Grand Cove near the contact between the medium to coarse grained acid pyroclastic rocks of the Grand Cove Sequence and the Pacquet Harbour Group. It is a fine grained light grey siliceous rock containing wispy fragments of slightly darker material. In thin section the light grey matrix was found to be very fine grained and composed mainly of quartz with minor amounts of untwinned felspar, biotite, muscovite and calcite. The possibly fragmental material is usually of medium grain size and more mafic in composition, containing about 20% biotite compared to about 10% in the matrix. Magnetite rich bands occur in the fragmental material. The biotite and muscovite were found to form a weak schistosity which did not contain the long axis of the fragments. In similar situations in the Pacquet Harbour Group a schistosity was noted parallel to the long axes of the fragmental material.

(b) Cape St. John Porphyry: Along southern marginal parts of the map-area from the longitude of Grand Cove westward to Southwest Brook is a belt of quartz-felspar porphyry called the Cape St. John Porphyry. This belt is part of a large quartz-felspar porphyry body which extends southward for approximately 15 miles and underlies an area of approximately 80 square miles. A similar body underlies a large area west of Southwest Arm in Green Bay (Neale - 1958 a).

The porphyry consists of subhedral phenocrysts of orthoclase and andesine (An 38) with anhedral phenocrysts of quartz in a fine grained quartz-felspar-biotite-muscovite matrix. The percentage of phenocrysts range from 30 to 65%. Also the relative percentages of phenocryst minerals are variable with no mineral consistently predominant. Schistose textures are less strongly developed than in the Cape Brule' Porphyry. The leucocratic minerals here and there show slight annealing effects but are generally only slightly recrystallized. The opposite of this is found in the Cape Brule' Porphyry. The micas, which comprise up to 35% of the matrix, show a single relatively poorly developed schistosity unlike the Cape Brule' Porphyry which usually shows two, the later of which is usually strongly developed.

This porphyry, like the Cape Brule' Porphyry, contains abundant xenoliths and small inclusions. These inclusions, instead of being predominantly pelitic and amphibolitic schists, are dark fine grained fragments which appear to be hornfelsic. Most of these inclusions exhibit weak cleavage rather than a well-defined schistosity. Some of the xenoliths show possible slight flattening effects but others do not appear to be deformed. (Plate II-3). Chloritic inclusions were seen locally.

Possible primary folds, of either intrusive or extrusive igneous banding, were noted on the LaScie road approximately one mile west of the Nipper's Harbour junction. These folds are rounded high amplitude short wave length structures developed on a non-tectonic compositional banding (Plate II-4). They die out vertically over a distance of a few feet in homogeneous quartz-felspar porphyry. The homogeneous rocks in which they are developed eliminate the possibility of them being tecton-

Plate II - 3. Primary banded quartz-felspar porphyry containing relatively undeformed xenoliths: Cape St. John Porphyry from the LaScie Road.

Plate II - 4. Primary folding in banded quartz-felspar porphyry: Cape St. John Porphyry from the LaScie Road.

ically formed ptygmatic folds. Similar or concentric folds seldom die our vertically in such short distances. Thus they are believed to be primary or slump folds.

This porphyry has close spatial and lithologic ties with the previously described Cape Brule' Porphyry which was originally included within it. The previously mentioned structural metamorphic and lithologic dissimilarities lead to the conclusion that they have different geological histories. In the writers opinion there are two possible ways to obtain this situation. One is that they are rocks of two different ages either in unconformable contact or brought into juxtaposition along a tectonic junction. The other possibility is that both units are part of the same large quartz-felspar porphyry body but belonging to different structural levels which were brought into juxtaposition by later tectonism. If the second theory is valid the age distinction between pre-Lower Ordovician and Silurian (?) rocks becomes invalid and all of the rocks in the area belong to the same succession but occupy different structural levels.

Chapter III. Structural Geology

A. Terminology:

(a) Deformation Ellipsoid and Tectonite Fabrics: The strain condition of a deformed rock is most conveniently represented by the shape and orientation of the deformation ellipsoid. This is the post deformational shape of an originally spherical passive body within the rock. The axes of this ellipsoid are termed Z,Y & X.

Flinn (1962, 1965) devised a convenient way of comparing all the different possible ellipsoids by plotting them on the deformation plot. He did this by calculating the ratios $a = Z/Y$ and $b = Y/X$ and plotting a against b. All possible ellipsoids were then represented by points on a graph. This arranges the ellipsoids systematically on the plot so that the greater they depart from spherical the farther they are from the origin. Also all prolate ellipsoids where $X = Y$ lie along the line $b = 1$, and all oblate spheroids where $Y = Z$ lie along the line $a = 1$. All ellipsoids lying along the line $a = b$ have no deformation parallel to the intermediate axis. This situation is called plane strain. All remaining ellipsoids are arranged systematically between these lines.

For an oblate spheroid where $Z = Y > X$ a k value of 0 is calculated where:

$$k = \frac{a - 1}{b - 1}$$

Similarly for a prolate ellipsoid where $X = Y < Z$ a k value of ∞ is obtained. Under conditions of plane strain the k value is 1. All other k values lie between these is a systematic manner.

During three-dimensional progressive deformation the orginal sphere goes through a series of infinitesimal deforming steps until the deformation ceases leaving the final deformation ellipsoid. The locus of the projections of these "incremental deformation ellipsoids", is known as the deformation path. The simplest deformation path is of the type:

$$k' = \frac{\log a}{\log b}$$

and $k' = k$ where $k = 1,\ 0\ \&\ \infty$.

It is possible to relate the k value of a deformation to the type of fabric produced by it. Thus Flinn (1965 (b)) invoked the use of the terms L,S and L-S tectonites when describing fabrics. The L and S fabrics are end members of a continuous series which varies from a perfect linear fabric (L) to a perfect planar fabric (S). All intermediate stages are called L-S fabrics. For a perfect L-fabric a k value of infinity is to be expected and for a perfect S-fabric the theoretical k value is 0. The intermediate stages of L-S fabrics k is between 0 and ∞.

(b) Classification of Folds: The terminology used in the description of folds is that used by Fleuty (1964 b). Folds having beds of more or less constant axial plane thickness are called similar folds. These are the equivalent of Donath & Parker's (1964) passive flow folds. Folds having constant orthogonal thickness are called concentric (parallel) by Fleuty and are the equivalent of Donath and Parker's flexural slip folds. Fleuty's terminology on degree of tightness was also used.

B. Structural Geology of the Pacquet Harbour - Grand Cove Area:

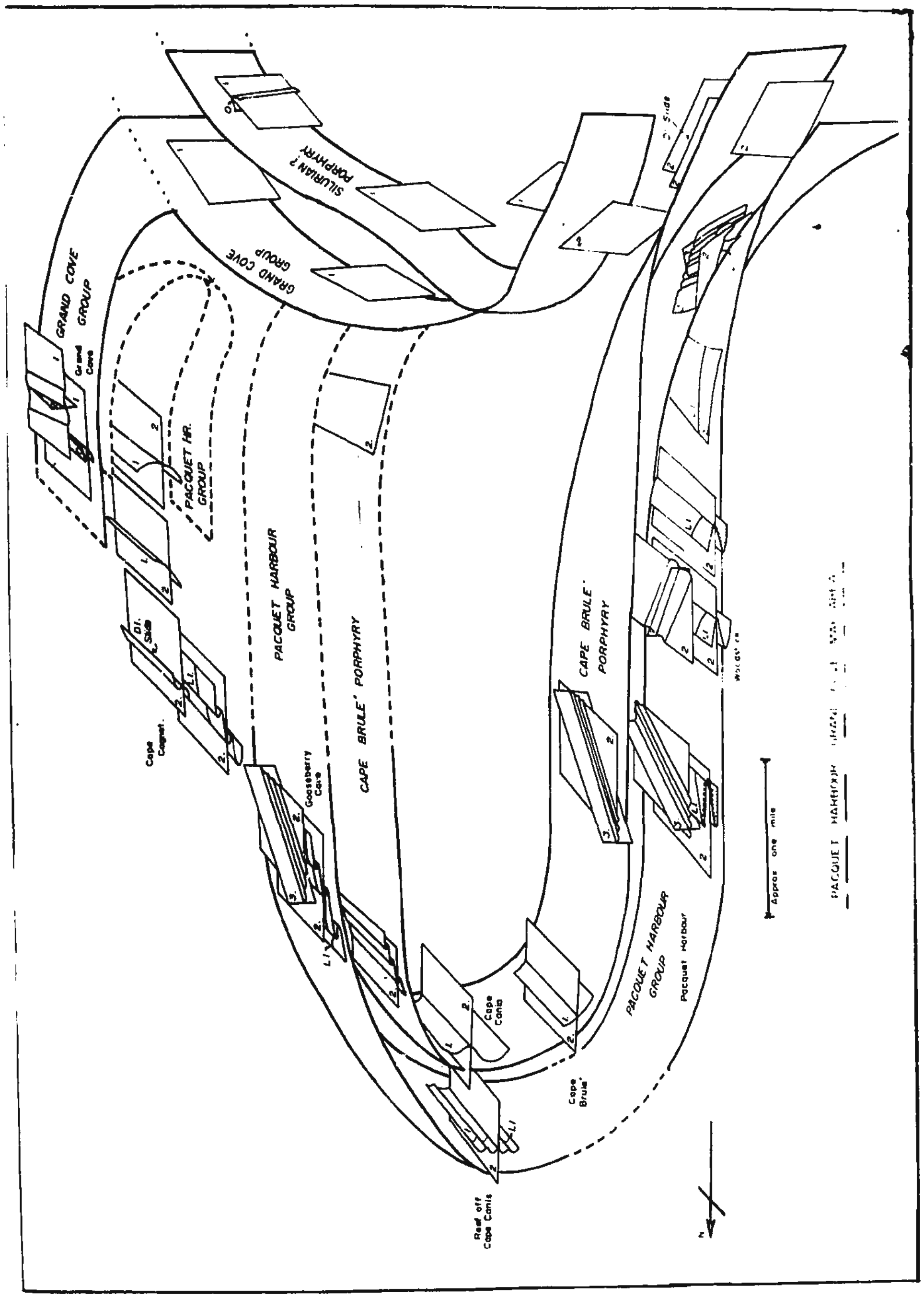


Fig III-1. Structural interpretation of the Pacquet Harbour - Grand Cove Area.

The Pacquet Harbour - Grand Cove area has undergone varying degrees of polyphase deformation and metamorphism during its geologic history making it divisable into two distinct tectono-metamorphic domains. Rocks of one domain show the effects of three early deformations. These were recognized in the Pacquet Harbour Group and the Cape Brule' Porphyry which constitutes one domian. The other domain shows the effects of one early penetrative deformation and a second local non-penetrative one. These were found developed in the Grand Cove Sequence and the Cape St. John Porphyry. At least two later deformations affected the whole area.

(a) Structures of the Pacquet Harbour Group and Cape Brule' Porphyry:

(i) The first deformation (D_1): The first deformation produced a penetrative L-S tectonite fabric (S_1). It varies from an almost pure L-fabric to a L-S fabric (S>L). The fabric is shown in the Pacquet Harbour Group by the preferred orientation of hornblende with minor biotite. In the Cape Brule' Porphyry it is chiefly a biotite fabric. In both groups the D_1 fabric is best seen in the hinges of major and minor folds related to the second deformation. On F_2 fold limbs S_1 and S_2 approach parallelism and S_1 becomes difficult to differentiate from S_2.

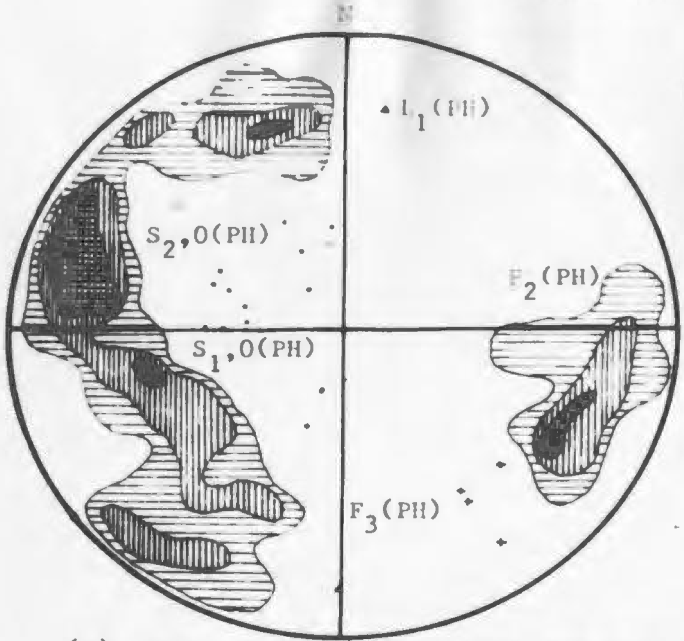
The orientation of the bulk strain axes of the D_1 deformation ellipsoid can be obtained from the D_1 fabrics. The Z-axis is parallel to the mineral lineation (L_1) which lies in the plane of S_1, X is perpendicular to the schistosity plane and Y is perpendicular to both. D_1 strain gauges were measured in various parts of the area both in the Pacquet Harbour Group (vesicles) and in the Cape Brule' Porphyry (small xenoliths). The measured k-value was always close to 0.5 and represented a flattened prolate ellipsoid. On Pelee' Point, Kennedy (personal communication) has seen vesicles representing the D_1 deformation ellipsoid folding around the hinge of an F_2 fold.

S_1 when found as discreet s-surfaces, usually in F_2 fold hinges, is sub-parallel to original bedding and banding. S_1 cannot be seen on F_2 fold limbs except as a transposed or partially transposed fabric. Minor F_1 folding is rare and was seen only as interference patterns which are similar to Type 1 patterns. (Ramsay, 1967, p 521) (Plate III-1). These structures are found in the hinge of a F_2 fold and are viewed more or less in the plane of S_2 which is essentially flat-lying. In order to obtain interference patterns such as these the axial planes of both folds with respect to their present orientation must be steep. This rules out the possibility of their being F_1-F_2 superimposed structures. It is therefore likely that they are a D_1 phenomenon. They could represent double fold axes related to D_1 if the k-value was greater than 1 (Flinn, 1962, p 406). Since no D_1 deformation elipsoid was found in the vicinity of these structures no definite conclusion can be stated. No boudinage which could be related to the first deformation was found in the area.

No major F_1 folds can be established in the area because there was no repetition of lithostratigraphic units older than that caused by the major F_2 folds.

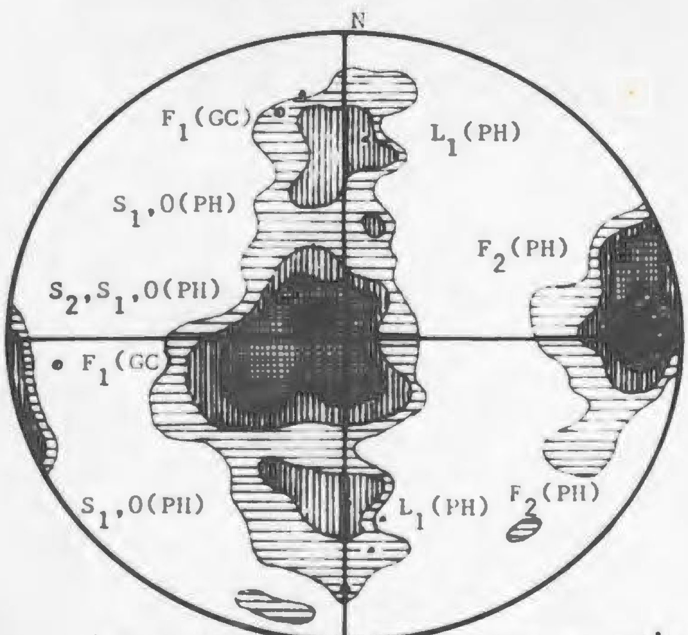
The only recognized large scale structural expression of D_1 were

Figure III - 2.

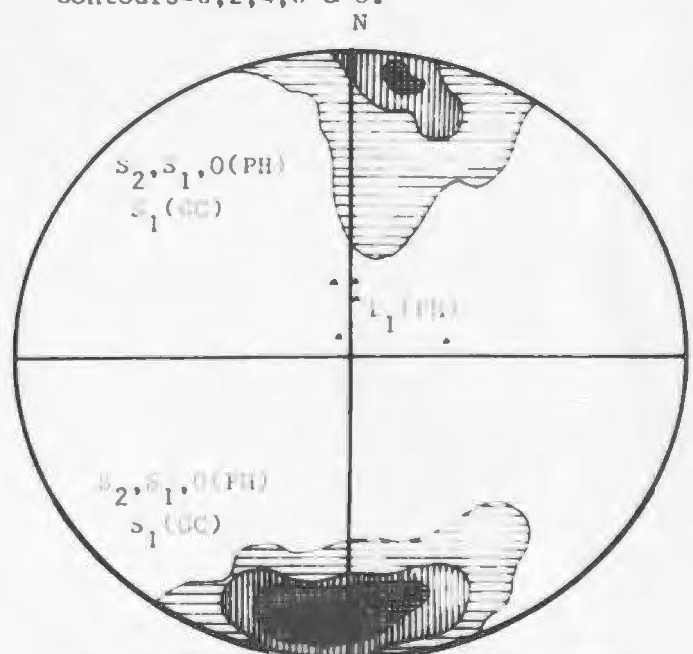


(a) Fold plunges, lineations and poles to S-planes in hinge of major F_2 recumbent fold; Cape Brule - Cape Canis area; Lower hemisphere equal area projection.
Points: $13F_2$, $4F_3$, $2L_1$, $13S_2$, $55S_1$(PH);
Contours-0,2,4, & 6%.

(b) Fold plunges, lineations and poles to S-planes on lower limb of major F_2 recumbent fold; Pacquet Harbour Group west belt; Lower hemisphere equal area projection.
Points: $8F_2$, $20L_1$, $50S_2$(PH);
Contours-0,2,4,6 & 8.



(c) Fold plunges, lineations and poles to S-planes on upper limb of major F_2 recumbent fold; Pacquet Harbour Group east belt; Lower hemisphere equal area projection.
Points: $43F_2$, $6L_1$, $42S_2$(PH); $2F_1$, $24S_1$,(GC):
Contours-0,2,4,8 & 12%.



(d) Lineations and poles to S-planes on steep limb of late monocline; Southern part of area; Lower hemisphere equal area projection
Points: $5L_1$, $40S_2$(PH); $50S_1$(GC)
Contours-0,5,10,15, & 20%.

(PH = Pacquet Hr. Group - GC = Grand Cove)

Plate III - 1. Interference patterns similar to Ramsey's Type 1 related to the first deformation . East belt of Pacquet Harbour Group.

Plate III - 2. Tight recumbent F_2 minor fold in semi-pelite from the structurally lower limb of this major F_2 northward closing recumbent fold. West belt of Pacquet Harbour Group.

tectonic slides (Fleuty, 1964 (b)) which were seen involving the Cape Brule' Porphyry. One good example is at the tip of Cape Cagnet where the actual slide plane is defined by a six foot wide quartz-felspar porphyry sill in amphibolite. The sill is intensely mylonitized but there are small zones where the porphyritic texture is preserved. The slide plane was later folded by F_2 folds. Another probable D_1 slide is found on the LaScie road at the contact between the Pacquet Harbour Group and the Cape Brule' Porphyry. There S_1 and S_2 are sub-parallel so the slide cannot be definitely established as a D_1 feature. This contact was observed in other places on the coast and showed similar mylonitic or highly schistose zones on major F_2 fold limbs which could not be dated with certainty.

(ii) The second deformation (D_2): The effects of this deformation are the most prominent in the area. It produced a strongly developed but not entirely penetrative sub-horizontal to vertical (section B(c)(i)- this chapter)) L-S fabric shown by a preferred orientation of hornblende and biotite. This fabric is best observed on the limbs of major and minor F_2 folds, as a S_1 - S_2 transpositional fabric. In the hinge zones of these folds it is usually seen as a strain-slip schistosity but in places it is not developed.

The minor folds related to the second deformation are recumbent to upright (Chapter III, B(c)(i)) similar folds which plunge gently to moderately to the south east. These folds are very common in all parts of the Pacquet Harbour Group and are represented in the Cape Brule' Porphyry. These fold axes show some variation in attitude across the area. (Fig. III - 2)

Plate III - 3. Open F_2 minor folds in hinge of major F_2 recumbent fold. Reef off Cape Canis.

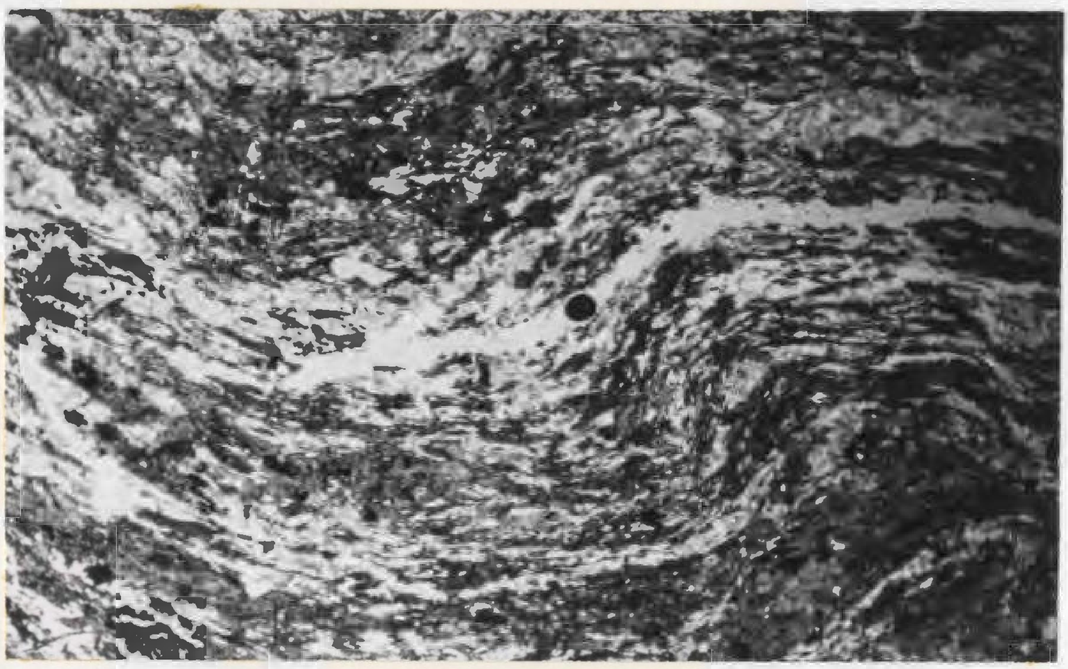


Plate III - 4. - (X 14) F_3 crenulations of S_2 in amphibolite from the West belt of the Pacquet Harbour Group. (uncrossed nicols)

No D_2 boudinage was recognized.

D_2 vergence, shown by the minor F_2 folds or by S_2/S_1-bedding intersections change in a systematic manner within the area indicating the presence of mjaor F_2 recumbent folds (Fig. III-1 and III-2). The F_2 minor folds are generally tighter in the major F_2 fold limbs than in the hinge areas. Minor folds in the west belt of the Pacquet Harbour Group are "tight" (Plate III-2) and their sense of vergence indicates they are developed on the lower limb of a major recumbent fold closing up to the north. Except in minor F_2 fold hinges S_2 is essentially parallel to S_1-bedding thus masking the latter. (Fig. III - 2(b)). Eastward in the region of Cape Brule' and Cape Canis there is a systematic increase in interlimb angles until the F_2 folds become "open". (Plate III - 3). S_1 now becomes the prominent fabric with S_2 only locally recognizable. (Fig. III - 2 (a)). In this region S_1 is steep. This is the hinge zone of the major F_2 fold. On the headland west of Gooseberry Cove "tight" F_2 folds indicate the upper limb of a northward closing major fold. Eastward along the coast the same structural position is maintained as far as Martin's Cove in Confusion Bay where S_1 is again prominent (Fig. III - 2 (c)) with a moderate northerly dip thereby indicating a position on the lower part of the hinge zone of a southward closing major F_2 fold.

The major folding as indicated by these observations can be described as a northward closing recumbent fold involving the Pacquet Harbour

Group and the Cape Brule' Porphyry. The upper limb of the structure continues into the lower part of the hinge of a related southward closing structure.

Facing directions on S_2 were obtained from the psammitic schists of the Ming's Bight Group which lies structurally conformably below the Pacquet Harbour Group and outcrops to the immediate west of the area. Graded bedding, consistent over a considerable distance, faces southward on S_2 (Shackelton, 1958). A few rather dubious graded beds were found in the west belt of the Pacquet Harbour Group showing the same southward facing directions. These "graded beds" now consist of sorted metamorphic hornblende and quartz and could be a direct result of metamorphism. However, if the facing directions of the Ming's Bight Group can be applied to the Pacquet Harbour Group and Cape Brule' Porphyry the structurally lower or northward closing major F_2 fold is a recumbent syncline and the southward closing fold is a recumbent anticline. (Fig. III-1)

(iii) The Third Deformation: (D_3): This deformation has no profound effects on the attitude of earlier structures. It produced crenulations (Plate III - 4) and local open concentric folds of the second schistosity. The F_3 folds usually plunge south-southwesterly along S_2 but in places are reoriented by later structures. No D_3 major structures have been recognized since earlier structures show no sign of folding on an axial plane of similar attitude to that of F_3. (Fig. III - 2)

(b) Structures of the Grand Cove Sequence and Cape St. John Porphyry:

(i) The First Deformation (D_1): The fabric associated with this deformation (S_1, Grand Cove) is a weakly penetrative S-tectonite fabric shown by the preferred orientation of biotite, muscovite, chlorite and sericite in rocks of the Grand Cove Sequence - Cape St. John Porphyry tectono-stratigraphic domian. This schistosity is similar in attitude to S_2 of the Pacquet Harbour Group and the Cape Brule' Porphyry but the actual contact is not exposed. However, the degree of development of this schistosity is less than that of S_2 of the Pacquet Harbour Group, and the metamorphism (Chapter IV) is different across the contact. It therefore seems unlikely that they are the same schistosity in direct contact. It is possible that they were formed by the same deformation and are now exposed on different structural levels brought into juxtaposition along either a syntectonic slide or a later thrust fault.

A k value close to zero is to be expected for the deformation. This was substantiated by one measurement of inclusions in the Cape St. John Porphyry.

Minor folding (F_1) related to this deformation was seen only in a few places in Grand Cove where primary planar features such as banding in pyroclastic rocks are present. The folds are tight recumbent similar folds with no apparent earlier schistosity being folded. No F_1 folds were found in the remainder of the structural domain but S_1 is everywhere evident. The absence of F_1 folding is believed to be due to the absence of small scale ductility contrast.

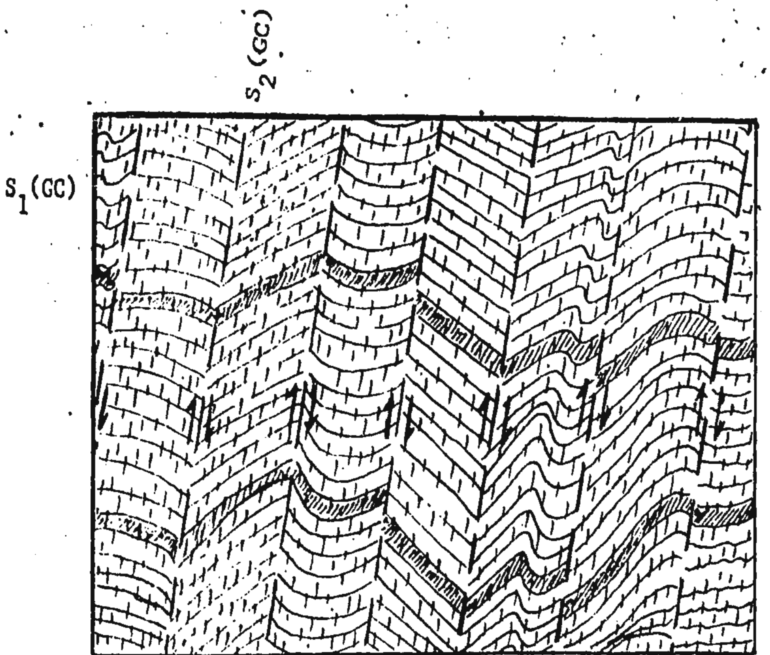


Fig. III - 3. Folding related to the second deformation of Grand Cove Sequence.

(ii) The Second Deformation (D_2): A well developed steep strain slip cleavage affecting S_1 (Grand Cove) was noted in the south-east corner of the area. This fabric could be traced southward into the interior of the Cape St. John Porphyry but not northward through the Grand Cove Sequence into the Pacquet Harbour Group. Thus its age relative to the structural history of the Pacquet Harbour Group remains obscure. It can only be established as later than the S_1 schistosity of the Grand Cove Sequence. Related to this fabric are locally developed angular minor folds here and there having slight displacements along their limbs parallel to S_2. (Fig. III - 3). These folds are very similar to the minute folds between the S_2 planes.

(c) Later fold Structures: These structural features are superimposed upon the features of both the structural domains previously described. Lack of comparative structural data makes it impossible to assign them a relative age.

(i) Monocline: In the southern part of the area the originally sub-horizontal S_2 (Pacquet Harbour) and S_1 (Grand Cove) becomes steeply southward dipping. This indicates the presence of an east west trending monoclinal structure. No apparent penetrative fabric is associated. Further evidence for the presence of the monocline can be obtained from Fig. III - 2(d) which shows a change in the orientation of both D_2 and D_3 structures (Pacquet Harbour) on its steep limb.

(ii) Kink Bands: Kink bands generally having a kinked segment length of one to three mm. are widespread in the Pacquet Harbour Group. These kink bands affect only an infinitesimal portion of the whole rock so the amount of shortening attributable to them is negligable in the area.

(d) Faults and Joints: Late faults showing small displacements and varying attitudes have been recorded in various parts of the area. A late fault with significant displacement occurs at Gooseberry Cove where gently dipping structures on the upper limb of the major F_2 (Pacquet Harbour) recumbent syncline are displaced a distance of a quarter mile. Since this fault is not thought to be large its greatest component of movement must have been dip-slip.

Jointing is widespread but no systematic study of it was undertaken. Many direction can be seen. The most prominent system is an east-west striking vertical set.

C. Summary of Structural History:

A synthesis of the structural geology of the Pacquet Harbour - Grand Cove map-area is presneted in Fig. III - 1. This schematic diagram with the series of stereograms is the structural interpretation of the area.

The first deformation D_1 (Pacquet Harbour) produced a well-developed penetrative L-S tectonite fabric. The minor folds related to D_1 were probably isoclinal similar structures. No major F_1 folds are present.

Tectonic slides are the only major structural features formed by D_1 within this area.

The second deformation, D_2 (Pacquet Harbour), produced the most prominent structural features. These include a well developed and locally non-penetrative sub-horizontal L-S fabric, (Fig. III-1 (a) (b) (c)) and minor F_2 folds. These folds are recumbent similar folds which change in style and sense of vergence from one limb of the major F_2 structure to another in a systematic manner within the area. D_2 vergence combined with facing directions indicate a major F_2 recumbent syncline and anticline (Fig. III-1). The dominant fabric changes from hinge to limb on the major folds. Figure III - 2 (a) shows the prominence of S_1 in the hinge of the major F_2 recumbent syncline and figure III - 2 (b) + (c) shows the prominence of S_2 on the limbs.

The third deformation, D_3 (Pacquet Harbour), produced local crenulations of S_2 and the related minor folds were open flexures of the same fabric. No major F_3 folds were noted and it can be seen from figure III - 2 (a) + (b) + (c) that the earlier structures were little affected by this deformation on a major scale.

The Grand Cove Sequence and the Cape St. John Porphyry were found to have lower grade metamorphism and a simpler structural history than the Pacquet Harbour Group and the Cape Brule' Porphyry. Deformation and recrystallization in these rocks was less intense. The geologic implications of these differences will be discussed in detail in Chapter V.

The first deformation of the Grand Cove Group produced a finer grained but penetrative s-fabric. Minor folds related to D_1 are recumbent similar folds which are rarely developed within the present map area. No major F_1 (Grand Cove) folds were recognized. A locally developed strain slip fabric subsequently affected the Cape St. John Porphyry but its age relative to the Pacquet Harbour structures is not known.

The whole area including the Pacquet Harbour Group and Cape Brule' Porphyry was folded by a post D_1 (Grand Cove) east west trending monocline which can be seen in Fig. III - 1 and also by comparing Fig. III-2(d) with Fig. III-2(a) (b) (c). Other late folding was in the form of locally developed small scale kink bands.

The last deforming forces to affect the area produced brittle effects shown by faults of variable attitude and small displacement.

Chapter IV. Metamorphism

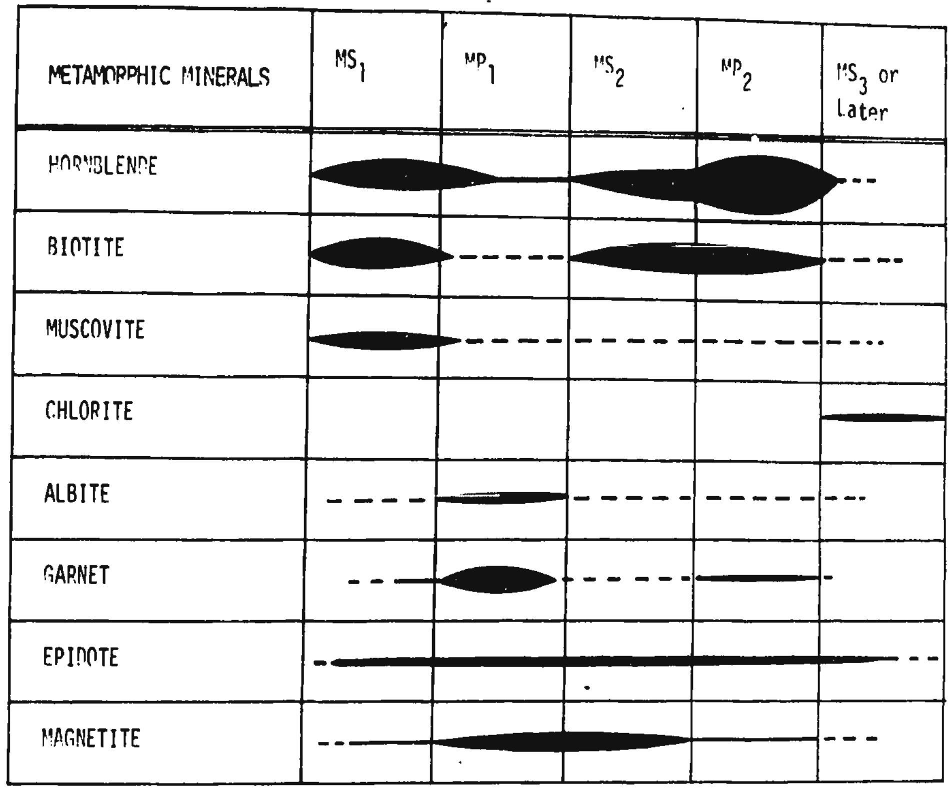
The rocks of the Pacquet Harbour - Grand Cove Map Area have undergone a complex metamorphic history. The most complex metamorphic history is associated with the highly deformed rocks of the Pacquet Harbour Group and the Cape Brule' Porphyry while the less deformed Grand Cove Sequence and Cape St. John Porphyry show a relatively simple history.

The metamorphic history of each tectono-metamorphic domain is shown by the growth phases of the various metamorphic minerals. The relative age of these growth phases relative to the previously established deformations was determined by detailed textural studies. The interpretation of these textures was based mainly on the work of Rast (1965).

Sturt and Harris (1961) in describing the polyphase metamorphic history of the Loch Tummel Area of the Scottish Dalradian employed a scheme of abbreviations which refer to the individual phases of mineral growth. The following scheme of abbreviations based on their work has been adopted to describe the metamorphism in the Pacquet Harbour - Grand Cove area.

	Phase of Mineral Growth	Movement
(a) Pacquet Harbour Group - Cape Brule Porphyry:		
MS_1	Syn-tectonic	D_1
MP_1	Post-tectonic	No deformations
MS_2	Syn-tectonic	D_2
MP_2	Post-tectonic	No deformations

PACQUET HARBOUR GROUP – CAPE BRULE PORPHYRY



GRAND COVE SEQUENCE – CAPE ST JOHN PORPHYRY

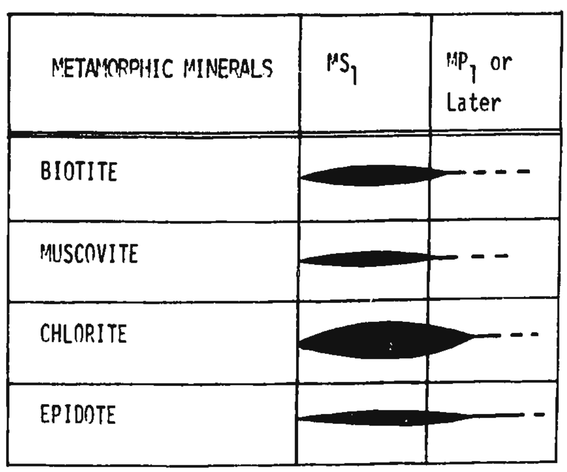


Figure IV-1 Growth phases of metamorphic minerals.

(b) Grand Cove Sequence - Cape St. John Porphyry:

MS_1	Syn-tectonic	F_1
MP_1	post-tectonic	No deformation

A. Metamorphic History of the Pacquet Harbour Group - Cape Brule' Porphyry Tectono-metamorphic Domain:

The most ubiquitous mineral in this domain is hornblende which shows a long growth history. Other minerals, such as garnet, albite, micas, magnetite and epidote, grew at various stages in the structural history. The other domain contains less variety both in metamorphic minerals and in growth stages. The main minerals are chlorite, biotite and muscovite. (fig. IV-I).

(a) Growth of Amphibole: Amphibole bearing rocks have resulted from the metamorphism of both basic igneous rocks and sedimentary rocks of the Pacquet Harbour Group and its xenolithic equivalents in the Cape Brule' Porphyry. The amphibole is generally hornblende. Minor actinolite was found associated with calcareous veinlets and segregations.

(i) Syntectonic growth: The tectonite fabrics associated with the first and second deformations are shown by preferred orientation of hornblende. The MS_1 growth is shown by a sub-linear orientation of hornblende c-axes (plate IV - 1). The MS_2 growth defines an L-S fabric. (Plate IV-2a)

The MS_1 hornblende has been often observed wrapping around minor F_2

Plate IV-1. (X 12) Section parallel to L_1 in lineated hornblende amphibolite from the west belt of the Pacquet Harbour Group. (X Nicols)

Plate IV-2(a). (X 30) MP_1 hornblende porphyroblast augened by MS_2 hornblende crystals. Note polygonal quartz fabric. (X Nicols)

Plate IV-2(b). (X 30) MP_1 hornblende containing magnetite inclusion trails of S_1 augened by the second schistosity. (X Nicols)

Plate IV-3. (X 14) MP_2 hornblende porphyroblast (right) containing magnetite inclusion trails showing S_2 as a strain-slip fabric on S_1 from the hinge of a major F_2 fold; Reef off Cape Canis. (plane light) fold hinges where MS_2 hornblende defines an axial planar schistosity. When observed in thin section the MS_1 hornblende in F_2 micro fold hinges was found to be slightly bent and to show incipient undulose extinction. This in interpreted as a strain effect on MS_1 hornblende during D_2. Since hornblende defines the D_1 fabric, it certainly nucleated during the first deformation but its grain size may have been considerably increased by later static growth.

(ii) Static growth: Hornblende porphyroblasts occur as a static MP_1 growth across S_1 before the second deformation and as post D_2 static growth (MP_2). Straight S_1 inclusion trails in amphibole porphyroblasts which are discontinuous with and augened by the second schistosity is conclusive evidence for MP_1 growth.(PlateIV-2(b)). The MP_2 growth contains straight inclusion trails which are oriented parallel to the second schistosity and are continuous with it. These porphyroblasts are not augened by S_2. Sometimes remnants of S_1 can also be found inside the MP_2 porphyroblasts. In one thin section of amphibolite from a major F_2 fold hinge remnants of both S_1 and S_2 can be clearly seen in large MP_2 hornblende porphyroblasts as magnetite inclusion trails. These magnetites show remnants of an S_2 strain-slip schistosity on S_1. (Plate IV-3)

MP_1 hornblende is limited in extent being observed in only a few sections. On the other hand the MP_2 growth has a profound effect on the whole area. This is especially true in the east belt of the Pacquet Harbour Group where MP_2 hornblende effectively masks most of the pre-existing

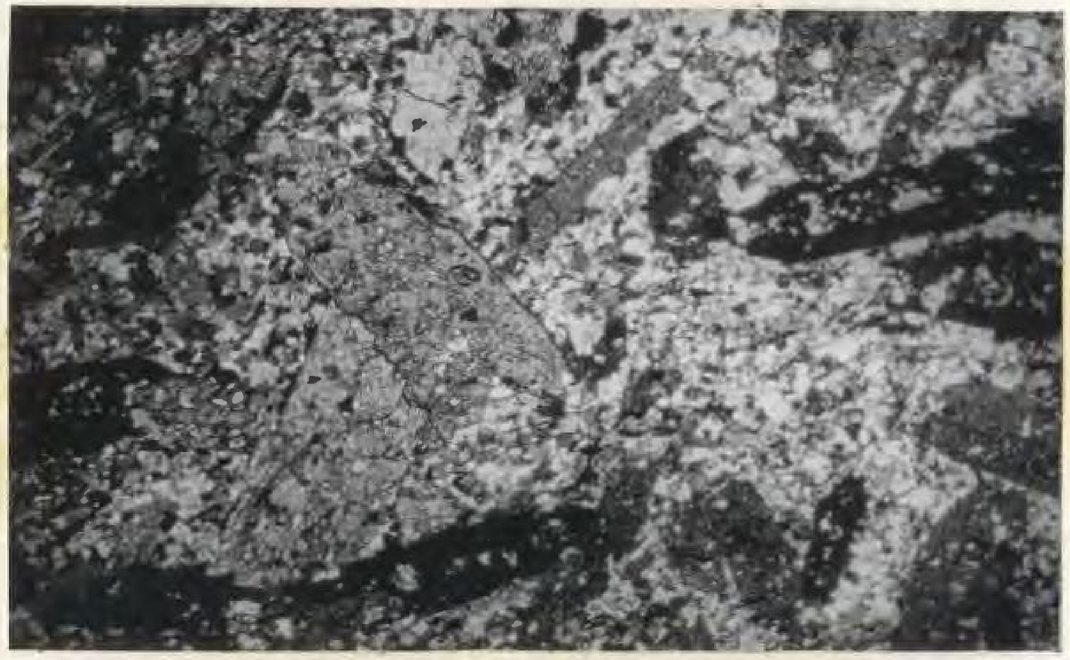


Plate IV-4. (X 15) MP_2 hornblende porphyroblasts containing an included quartz fabric of the same grain size as the matrix. (X Nicols)

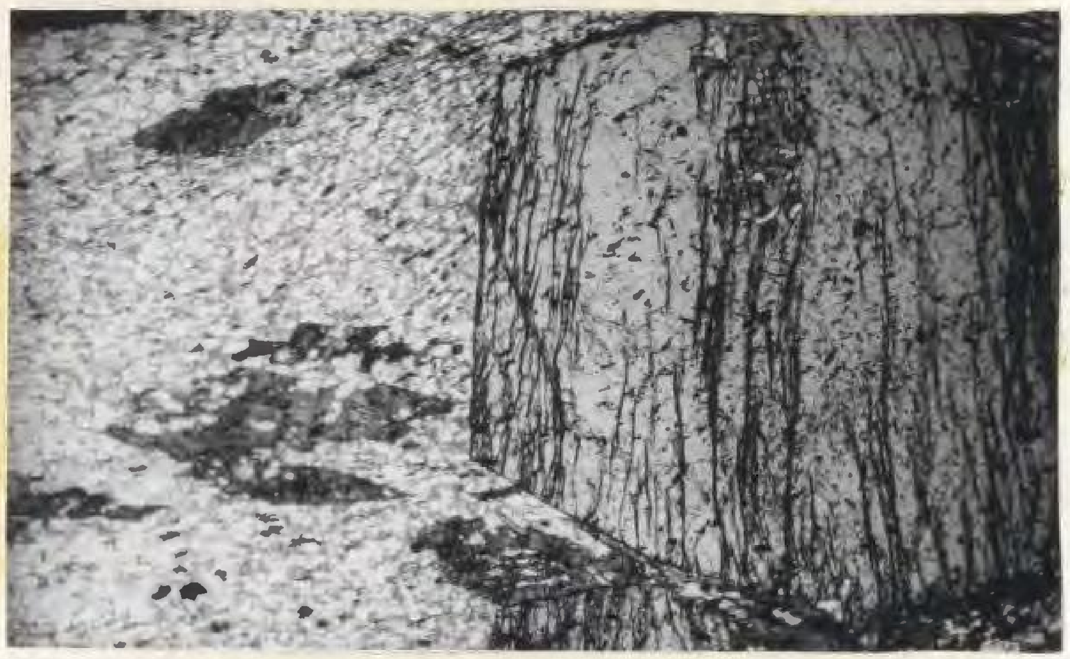


Plate IV-5. (X 14) MP_1 garnet porphyroblast containing straight magnetite inclusion trails of S_1 augened by the second schistosity; West belt of the Pacquet Harbour Group. (plane light)

Plate IV-6(a). (X 60) MP_1 garnet porphyroblast in quartz-felspar porphyry augened by the second schistosity. Note bent biotite in upper right corner of the porphyroblast; Cape Brule' Porphyry from Gooseberry Cove. (X-Nicols)

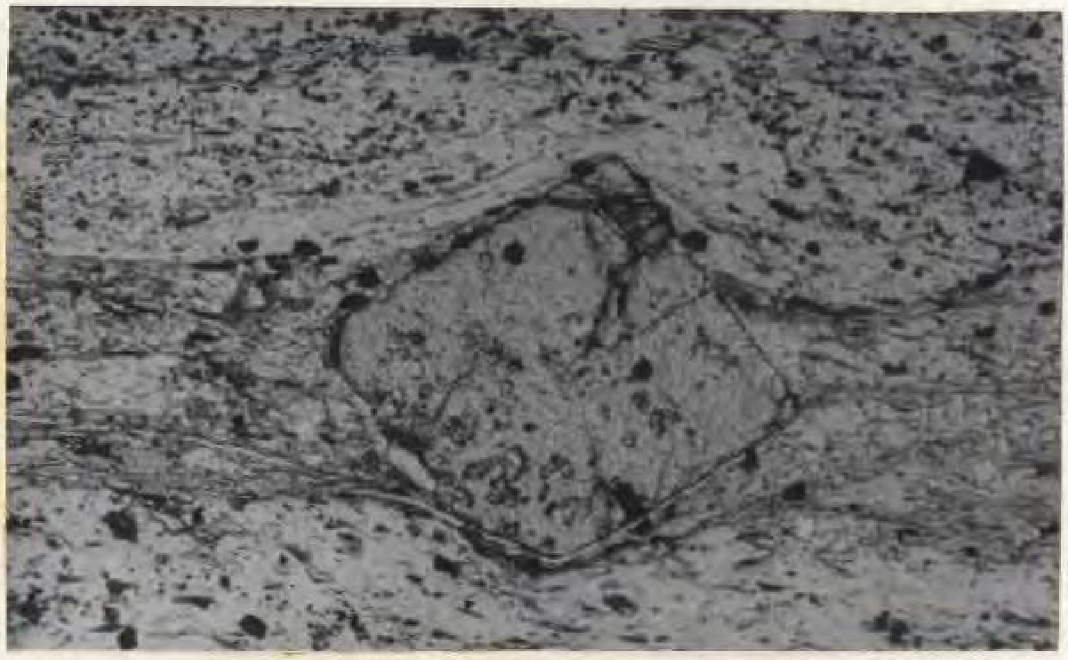


Plate IV-6(b). (X 65) MP_1 garnet porphyroblast augened by S_2 from fine grained quartz-biotite-felspar-magnetite schist; East belt of the Pacquet Harbour Group. (plane light)

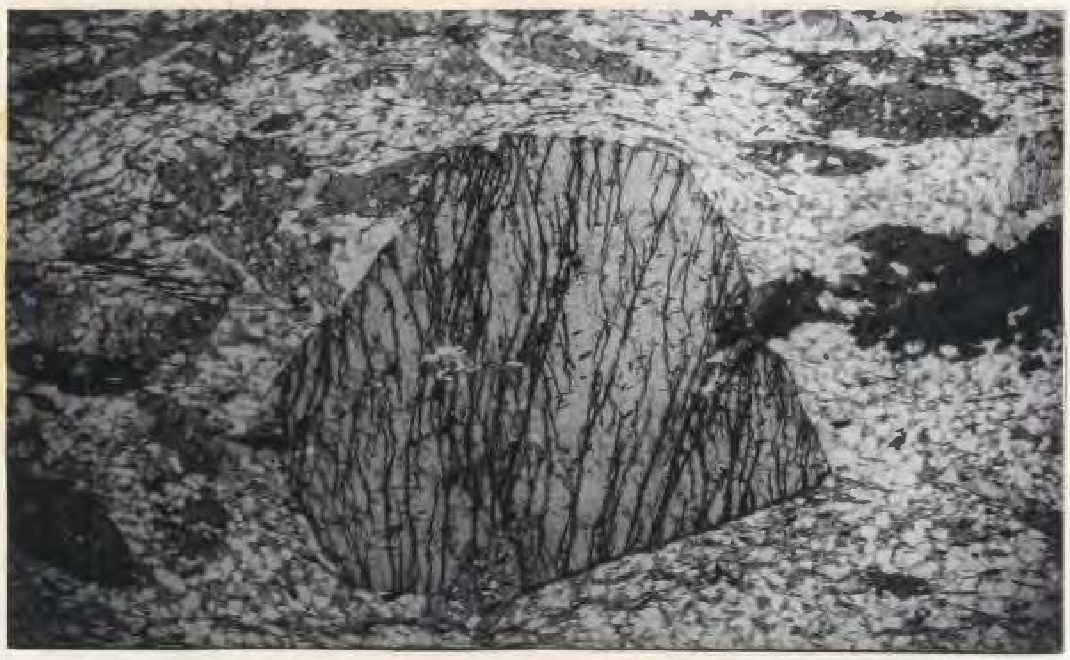


Plate IV-7. (X 14) Garnet porphyroblast shows a straight MP_1 core. Curved inclusions in the bottom left of the picture represents a static MP_2 growth over the D_2 augen; West belt of the Pacquet Harbour Group (plane light)

Plate IV - 8 - (X 35) Epidote-plagioclase replacement of garnet. Note vague duodecahedral outline. Augened by S_2: From east belt of Pacquet Harbour Group. (X Nicols)

Plate IV - 9 - (X 14) Cape Brule' Porphyry with sutured and embayed phenocrysts. The finer grained groundmass is completely annealed. (X Nicols) tectural phenomena making them only locally recognizable. These porphyroblasts are generally large (up to 3 centimeters in length) and randomly oriented. These porphyroblasts contain an included quartz fabric which has the same grain size as the quartz and felspar in the matrix. (Plate IV-4)

(b) Growth of Garnet: Garnet is only found in a few places. It occurs in both the Pacquet Harbour Group and the Cape Brule' Porphyry.

(i) Static growth: All garnets observed in the area are static growth porphyroblasts which grew either between the first and second deformation (MP_1) or after the second deformation (MP_2).

MP_1 garnet is the most commonly observed growth phase. Some porphyroblasts contain straight magnetite inclusion trails which are inclined to and augened by the second schistosity (Plate IV-5). Others contain no linear or curved inclusion trails but are augened by S_2. (Plate IV-6(a) & 6(b)). In one section, both MP_1 and MP_2 growth phases were seen in single crystals containing open Z-shaped inclusion trails. (Plate IV-7) The straight inner core inclusion trails oriented at an angle to S_2 represents MP_1 growth. The outer rims of these garnets overprint the D_2 augen effects and thus represent the MP_2 stage.

Epidote-plagioclase replacements of garnet sometimes having pseudomorphic dodecahedral crystal form are common in the Pacquet Harbour Group (Plate IV-8)

These pseudomorphs although now lacking inclusion trails still show an S_2 augen. They are interpreted as pre-D_2 garnets which have undergone subsequent alteration.

(c) Growth of Micas: Biotite is an important constituent of the amphibolites of the Pacquet Harbour Group where it occurs with and shows a similar growth history as hornblende. The Cape Brule' Porphyry contains biotite and less commonly muscovite. Chlorite occurs as a static retrogressive alteration of biotite.

(i) Syntectonic growth: MS_1 and MS_2 growth of biotite is associated with and has the same textural characteristics as the contemporaneous hornblende. (Chapter IV A (a) (i))

(ii) Static growth: No biotite which could be definitely established as a static growth phase was seen in the area. However there is a possibility that some of the syntectonic biotite may have been enlarged in grain size by later static growth.

(d) Growth of Quartz: Quartz is an important constituent of all rocks of the Pacquet Harbour Group and the Cape Brule' Porphyry. In the Pacquet Harbour Group it usually occurs as a fine to medium grained crystalline aggregate exhibiting a polygonal fabric. In the Cape Brule' Porphyry there are two types of quartz fabrics. The fine grained groundmass is annealed indicating textural equilibrium. The large phenocrysts on the other hand exhibit sutured and embayed grain boundaries indicating that the annealing process has not been completed and that they are in a state of textural disequilibrium, (Plate IV-9). The fact that both textural equilibrium and disequilibrium features occur in the same rocks seem to be due to the difference in grain size of the minerals being affected. The relative age or ages of these minerals are not known. Since quartz is relatively mobile under the metamorphic conditions found in this tectono-metamorphic domain it could occur from MS_1 to MP_2 quite possibly the actual growth stages now seen may be largely MP_2.

(e) Growth of felspar: Felspar is an important mineral constituent of both the Pacquet Harbour Group and the Cape Brule' Porphyry. It usually occurs in textural association with quartz. It is thus believed to be, like quartz, representing MP_2 growth. A few albite porphyroblasts have been noted in the Pacquet Harbour Group. These porphyroblasts are now recrystallized and appear as granular blobs which are augened by the second schistosity. Any inclusion trails which they may have contained are obliterated making it possible only to assign them a pre-MS_2 age. (Plate IV-10)

(f) Growth of Epidote: Epidote is a minor constituent of all rocks of this domain. It occurs usually as tiny crystals and aggregates which are usually spatially related to quartz and felspar rather than schistosity defining minerals such as hornblende and biotite. Metamorphic growth phases of epidote were probably in existence throughout the metamorphic history of the domain. It is also possible that some of it may be due to the process of sausuritization. Some of it may even be original accessory epidote.

Plate IV-10. (X 40) Annealed albite porphyroblast in amphibolite showing an S_2 augen; From the west belt of the Pacquet Harbour Group. (X Nicols)

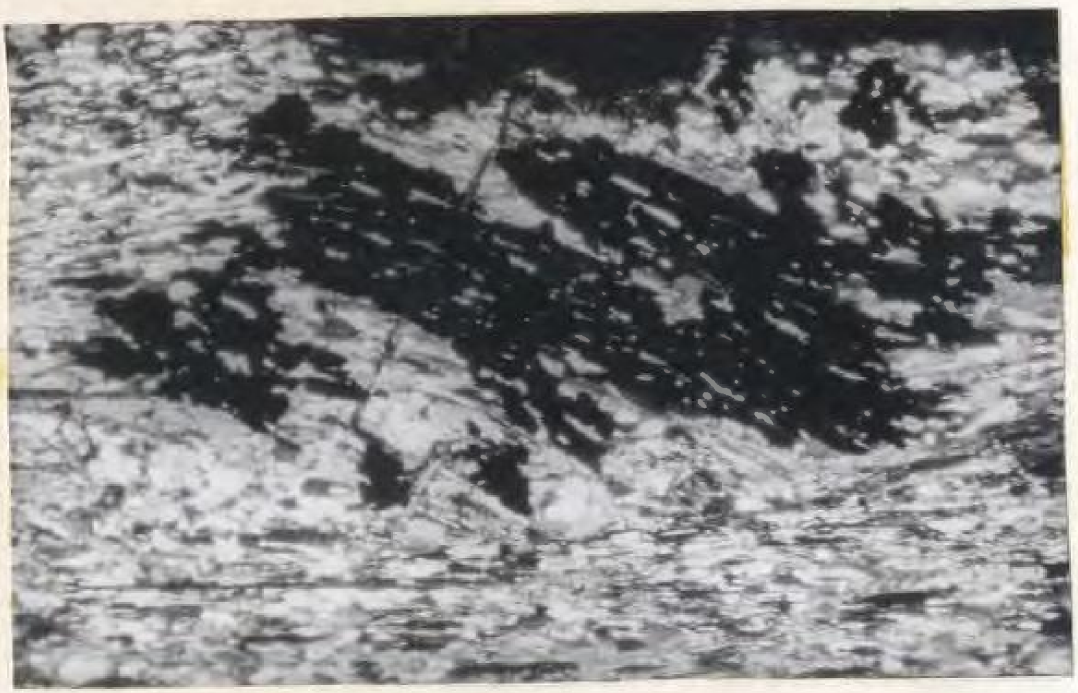


Plate IV-11. (X 40) Magnetite Porphyroblast containing static MP_1 growth in the center and dynamic MS_2 growth in its outer portion; West belt of the Pacquet Harbour Group. (X Nicols)

A few MS_1 hornblende crystals were seen to contain tiny epidote inclusions. No other dated epidote inclusions were seen. Epidote-plagioclase replacements of garnet are common in the Pacquet Harbour Group. (Chapter IV-Section A(b)(i))

(g) Growth of Magnetite : Magnetite has a long history of growth in the present area. Two crystal forms of magnetite were recognized. Octahedra averaging about 1/2 a centimeter across are the most common, Less commonly observed, but texturally very important, are anhedral grains, which are elongated parallel to and often contain inclusion trails of the planar fabrics. Much of this magnetite is probably original and later recrystallized.

(i) Static growth: Magnetite porphyroblasts occur as static growth on the first and second schistosities. Both MP_1 and MP_2 porphyroblasts show the same textural relationships as hornblende. (see Chapter IV-Section A (a)(ii).

(ii) Syntectonic growth: Magnetite grew during the second deformation (MS_2). The best evidence for this phase of growth comes from a specimen of lineated amphibolite from the west belt of the Pacquet Harbour Group. One porphyroblast containing a straight MP_1 inclusion trail pattern was found to have an outer rim containing a curved pattern. (Plate IV-11) The overall effect was an open S-shaped pattern with a straight central part. The curved part is indicative of dynamic growth during the second deformation and shows the various stages of continuous rotation until the S_2 plane was reached.

(h) Mineral Growth with respect to the third deformation: Throughout the preceeding sections there has been an apparent lack of data on mineral growth with respect to the third deformation. No metamorphic minerals which could definitely be associated with it were found during the present textural study. Since this deformation produced only crenulations and local minor open concentric folds it is almost certain that few metamorphic minerals can be related to it. It is possible that minor chlorite, epidote and biotite may have grown during D_3.

B. Metamorphic History of the Grand Cove Sequence - Cape St. John Porphyry Tectono-metamorphic Domain:

This domain has undergone a relatively simple metamorphism when compared to the one just described (Fig.IV-1). A lack of porphyroblasts is characteristic. The metamorphic minerals are muscovite, biotite and chlorite which have grown parallel to the first schistosity.

(a) Growth of Biotite and Muscovite: Micas are found throughout the Grand Cove Sequence and the Cape St. John Porphyry. Biotite is the chief mica. Muscovite is also frequently found in close association with it. These micas define the first schistosity of this domain and are thus considered to have grown during its first deformation (MS_1). A few tiny randomly oriented micas suggest the possibility of there being some post-tectonic nucleation and growth.

(b) Growth of Chlorite: Lying in apparent structural conformity with the acid rocks of the Grand Cove Sequence just outside the south eastern margin of the area is a band of vesicular basic lava mapped as part of the Cape St. John Group by Neale (1958). This shows the same structural history as the Grand Cove Sequence. Attention is brought to this unit because it is compositionally similar to the basic volcanics of the Pacquet Harbour Group. However its metamorphic features are very different. The schistosity is defined by flaky euhedral chlorite crystals (MS_1) instead of amphibole which pervades the Pacquet Harbour Group.

(c) Growth of Quartz: The Grand Cove Sequence and the Cape St. John Porphyry exhibit weakly developed sutured grain boundaries and embayments in quartz. This fabric is widespread but usually does not destroy the original textural phenomena. This recrystallization of quartz probably is related to the first deformation.

(d) Growth of Epidote: Epidote is a common constituent of these rocks. The exact age of this epidote is uncertain but a substantial amount is believed to be related to the growth phase MS_1.

C. Summary and Comparison of Metamorphic Histories:

The Pacquet Harbour Group and Cape Brule' Porphyry underwent metamorphism near the boundary between the highest temperature greenschist and the lowest temperature amphibolite facies throughout all phases of its metamorphic history up to MP_2. In terms of the Barrovian - Type Facies Series outlined by Winkler (1965) this corresponds to the boundary between the Almandine-Amphibolite facies and the quartz-albite-epidote-almandine subfacies of the greenschist facies. The metamorphosed basic rocks of the Pacquet Harbour Group have the chief minerals of Winkler's assemblage, "Hornblende + plagioclase + epidote ± almandine ± biotite ± quartz", throughout the stages from MS_1 to MP_2. Another typical assemblage of this P-T range was found in the Cape Brule' Porphyry. It consisted of biotite, muscovite, almandine (?), quartz and epidote.

The only plagioclase actually observed in this domain was albite (An 0-5), but this may only be a late feature. In view of the fact that no oligoclase was actually seen one is tempted to place the rocks into the high temperature greenschist facies. However, Kennedy (personal communication) has pointed out that in parts of the Fleur de Lys Group plagioclase porphyroblasts are found with albite actually replacing oligoclase. In view of this no distinction between upper greenschist and lower amphibolite was made for the early phases of metamorphism. It also should be pointed out that no work on the actual compositions of garnet was done so they are therefore not necessarily almandine.

The Grand Cove Sequence and the Cape St. John Porphyry contain the assemblage biotite-muscovite which is not distinctive of any facies in the lower grades of metamorphism. The overall state of preservation of the rocks indicate a lower metamorphic grade than that found in the Pacquet Harbour Group and Cape Brule' Porphyry. A basic lava of the Cape St. John Group which occurs in structural conformity with the Grand Cove Sequence was found to contain major amounts of chlorite which is typical of only the lower or middle temperature part of the greenschist facies. On the basis of these relationships a lower or middle temperature greenschist facies metamorphism is assigned to the Grand Cove Sequence and the Cape St. John Porphyry.

Chapter V. SUMMARY & CONCLUSIONS

A. Summary of Geological History

The oldest rocks recognized in the area are the basic meta-volcanic rocks of the Pacquet Harbour Group. Intrusive into these before their first deformation is a body of quartz-felspar porphyry known as the Cape Brule' Porphyry. Three deformations and complex metamorphism affected both units before early Ordovician time. (Chapter 1 (c)). This first deformation produced a L-S tectonite (L>S) and tight to isoclinal similar folds of unknown attitude. These folds have not been seen in the areas but are found on Pelee' Point and at various other localities in the Fleur de Lys Supergroup. The only large scale expressions of this deformation were tectonic slides. These D_1 features were then deformed by a second deformation which produced a well developed S-fabric associated with both major and minor F_2 recumbent similar folds. The third deformation (D_3) produced open upright flexures and crenulations of the second schistosity. Metamorphism from the beginning of the first deformation until post D_2 was in the order of high temperature greenschist to low temperature almandine amphibolite facies. The climactic episodes of metamorphism were the MP_1 and MP_2 phases. Data on metamorphic mineral growth with respect to D_3 is lacking but a substantially lower grade is suspected.

In unconformable or tectonic contact with the above tectono-stratigraphic unit is a belt of acid volcanic and pyroclastic rocks called the Grand Cove Sequence. This lies in structurally conformable contact with a quartz-felspar porphyry called the Cape St. John Porphyry. These two units have a less complex structural and metamorphic history than the previously described rocks and are correlated with the Cape. St. John Group (Silurian (?)) as described by Neale (1958). The first deformation to affect them produced a penetrative but weak S-tectonite fabric with local tight recumbent similar folds. No major F_1 folds were recognized. The second deformation was a locally developed steeply dipping strain-slip cleavage with no related major folds. The metamorphism in this domain is lower greenschist or chlorite grade and its associated mainly with the first deformation of the sequence.

The whole area was subsequently folded by an east west trending monoclinal structure. This resulted in a northern flat belt of schistosity and a steep belt to the south of the area. Later minor faulting is common throughout the area.

B. Regional Correlations:

The preceeding chapters, summarized in section A of this chapter, have shown that there are two distinct geologic units within the map area. Since the Burlington Peninsula is, except for the Snook's Arm Group, barren of fossils most regional correlations must be made on the basis of structural, metamorphic and lithological evidence. Evidence obtained from the present investigation lends support to the recognition of the Pacquet Harbour Group as part of the same metamorphic complex as the Ming's Bight Group and the Fleur de Lys Group. It also suggests that the Grand Cove Group is part of the Cape St. John Group and therefore does not warrant group status so the name Grand Cove Sequence is proposed. It is also proposed that the Cape

Brule' Porphyry as mapped during the present study was intruded before Lower Ordovician times. The name Cape St. John Porphyry is proposed for another porphyry body which was thought to be the same as the Cape Brule' Porphyry but was found to have the same structure and metamorphism as the Cape St. John Group.

(a) Pacquet Harbour Group - Ming's Bight Group - Fleur de Lys Group Correlation: This regional correlation was first suggested by Church (1967) who also considered the Grand Cove and Cape St. John Groups as part of the same conformable sequence. Neale and Kennedy (1967) supported the Pacquet Harbour - Ming's Bight - Fleur de Lys correlation but reinterpreted the Cape St. John Group as a younger Silurian (?) sequence.

The Pacquet Harbour - Ming's Bight and Fleur de Lys Groups have more of less identical early structural and metamorphic histories. The first deformation of these rocks produced tight to isoclinal folds with a penetrative S_1 schistosity. D_1 tectonic slides have been recognized in the Fleur de Lys Group (Phillips et.al.,1969) and also in the Pacquet Harbour Group (Chapter III, Section A (4)). An MP_1 metamorphic climax attaining amphibolite facies metamorphism is common to both groups. The second deformation of the Pacquet Harbour Group produced tight southward facing major recumbent similar folds with a strong axial planar schistosity. The second deformation of the Fleur de Lys Group produced the same structures but with a northward facing direction. MS_2 and MP_2 metamorphism was at or near the amphibolite facies for both groups. These are the major tectonic and metamorphic events in both groups. Several later minor or local deformations were recognized in both.

No detailed work has yet been done on the structural and metamorphic history of the psammitic schists of the Ming's Bight Group which conformably underlie the rocks of the Pacquet Harbour Group. Brief reconnaissance along its coastal section between Pacquet Harbour and Ming's Bight showed that the structural history (D_1, D_2, D_3) is common to both. A southward D_2 facing direction was also found in the Ming's Bight Group.

(b) Grand Cove Sequence - Cape St. John Correlation: These rocks contain the same early structural and metamorphic events and are therefore believed to belong in the same tectono-stratigraphic unit. The first deformation of the Grand Cove Sequence produced a weakly penetrative S_1 schistosity and a few minor recumbent folds. The second deformation formed locally well developed strain-slip cleavage with a few related minor folds. Metamorphism reached lower to middle greenschist facies conditions. The second deformation produced a strain-slip cleavage which is developed in both groups.

There is a sharp contrast in metamorphism, structure, and lithology across the junction between the Grand Cove Sequence and the Pacquet Harbour Group. Also there is a truncation of lithologic units on both sides of the contact (see map). This evidence leads to the conclusion that the contact is not conformable as suggested by Church (1967, 1969) who has shown the east belt of the Pacquet Harbour Group as Grand Cove Group. Since lithologic units are truncated on both sides a tectonic junction or an unconformity is more likely. The actual junction was not observed in the area.

(c) Age Problem of the Cape St. John Group: The Cape St. John Group was first proposed as a geologic unit by Baird (1951) and Neale and Kennedy (1967) correlated with the dated Silurian Botwood and Springdale Groups. Church (1967) eliminated the name Cape St. John Group for the rocks of Grand Cove and named these rocks the Grand Cove Group which he considered a conformable part of the Fleur de Lys Supergroup. The present investigation shows that ideas presented both by Church and by Neale and Kennedy have some basis in fact. Evidence shows that Neale and Kennedy were probably right in suggesting that the Cape St. John Group has a different geological history than the Fleur de Lys Supergroup but not to the point of placing it in the Silurian. Other evidence shows that Church may be right in considering the Cape St. John as part of the Fleur de Lys Supergroup but not in the conformable sequence that he proposes. The structural and metamorphic history of the Grand Cove Sequence is less complex and lower grade than that of the Pacquet Harbour Group. This is interpreted as the result of exposure of the Grand Cove Sequence on a higher structural level than the Pacquet Harbour Group. Since they are not in stratigraphic succession (see map) the contact is most probably tectonic, either a D_2 tectonic slide or a later thrust which was subsequently folded by a monocline.

The two quartz-felspar porphyrys mentioned in this report have close spatial and compositional association coupled with a structural and metamorphic differences. It is possible that they might in fact be part of the same body but exposed on different structural levels. If this is true the Cape St. John Group would be of similar age to the Fleur de Lys Supergroup. Other evidence for this conclusion comes from the Sncok's Arm Group - Cape St. John Group junction on the eastern side of the Burlington Peninsula. Upadhyay (personal communication) has stated the possibility that the dated lower Ordovician Snook's Arm Group is younger than the Cape St. John Group in that area. He bases this conclusion on sharper differences in degree of deformation across the contact. The Snook's Arm Group contains a relatively simple structural and metamorphic history while the adjacent Cape St. John Group has a penetrative schistosity and higher grade metamorphism.

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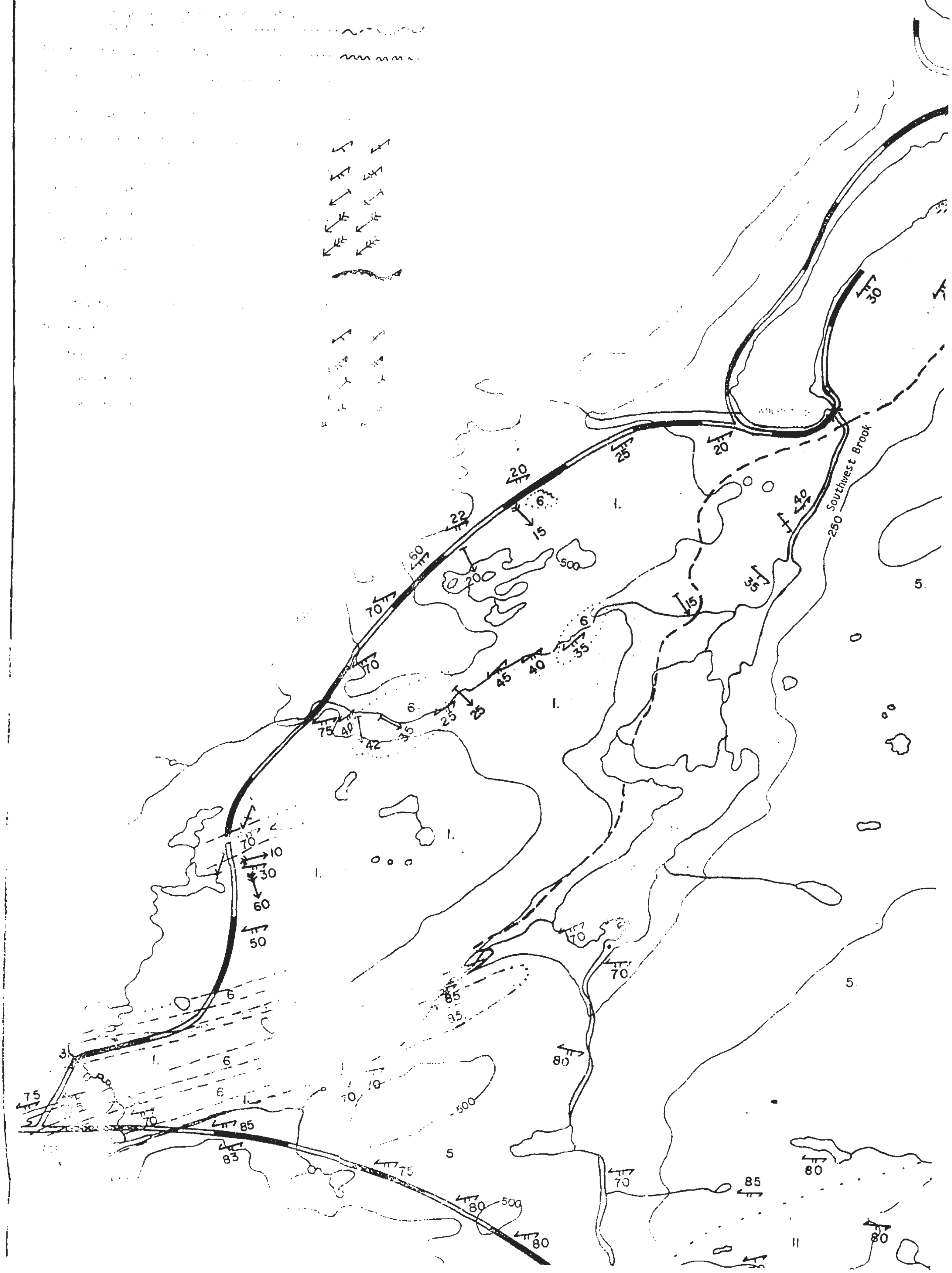
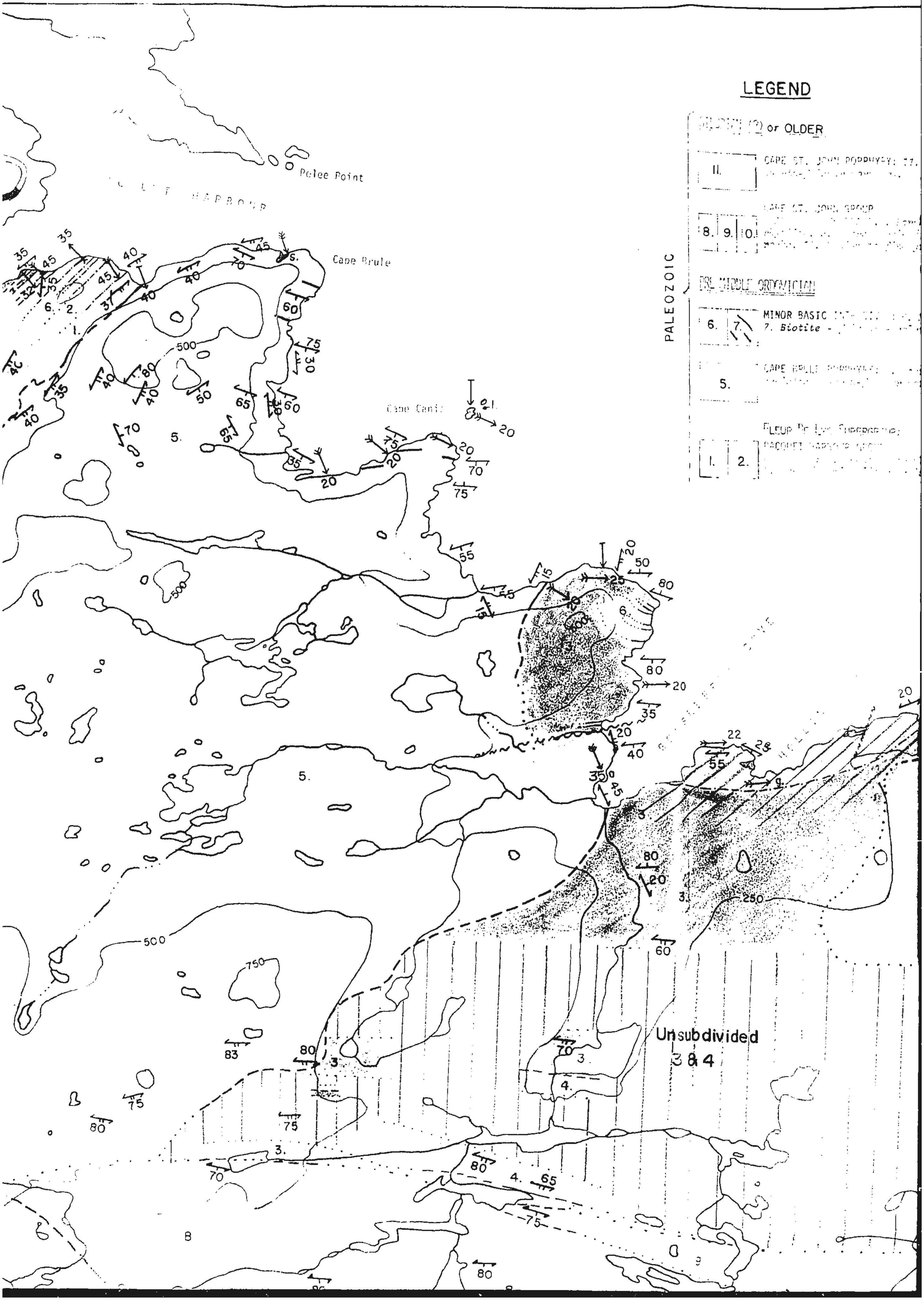
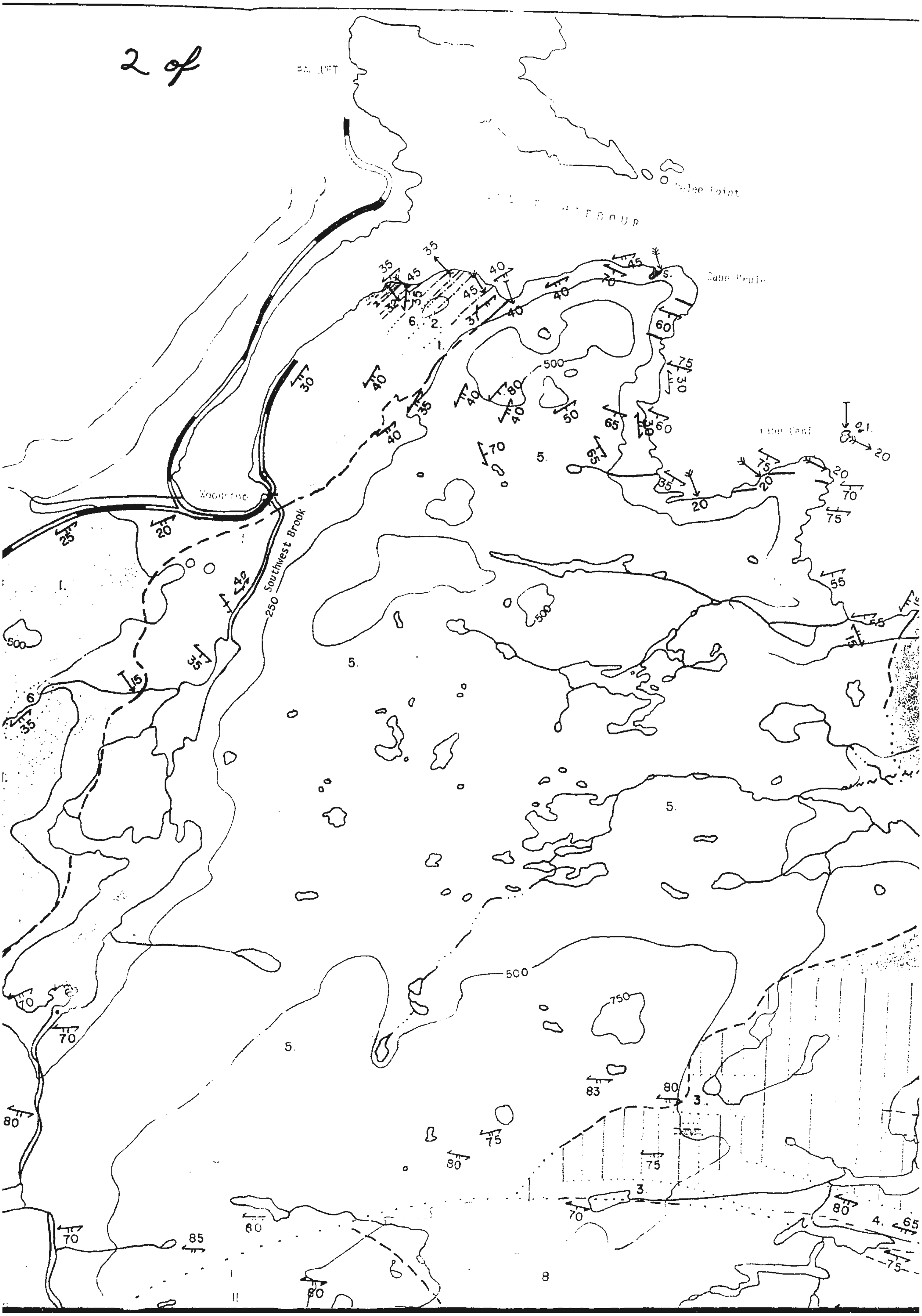
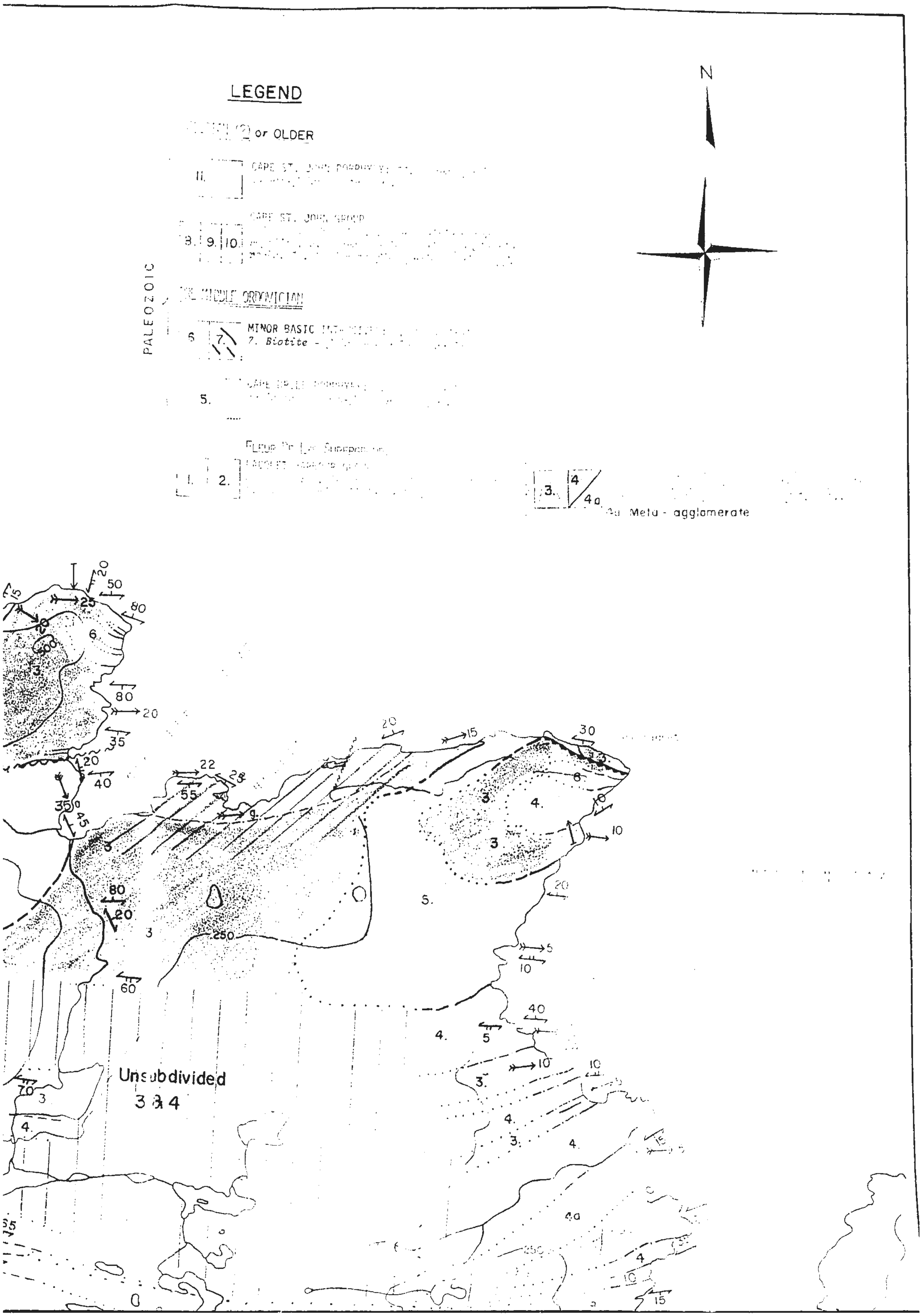
SYMBOLS



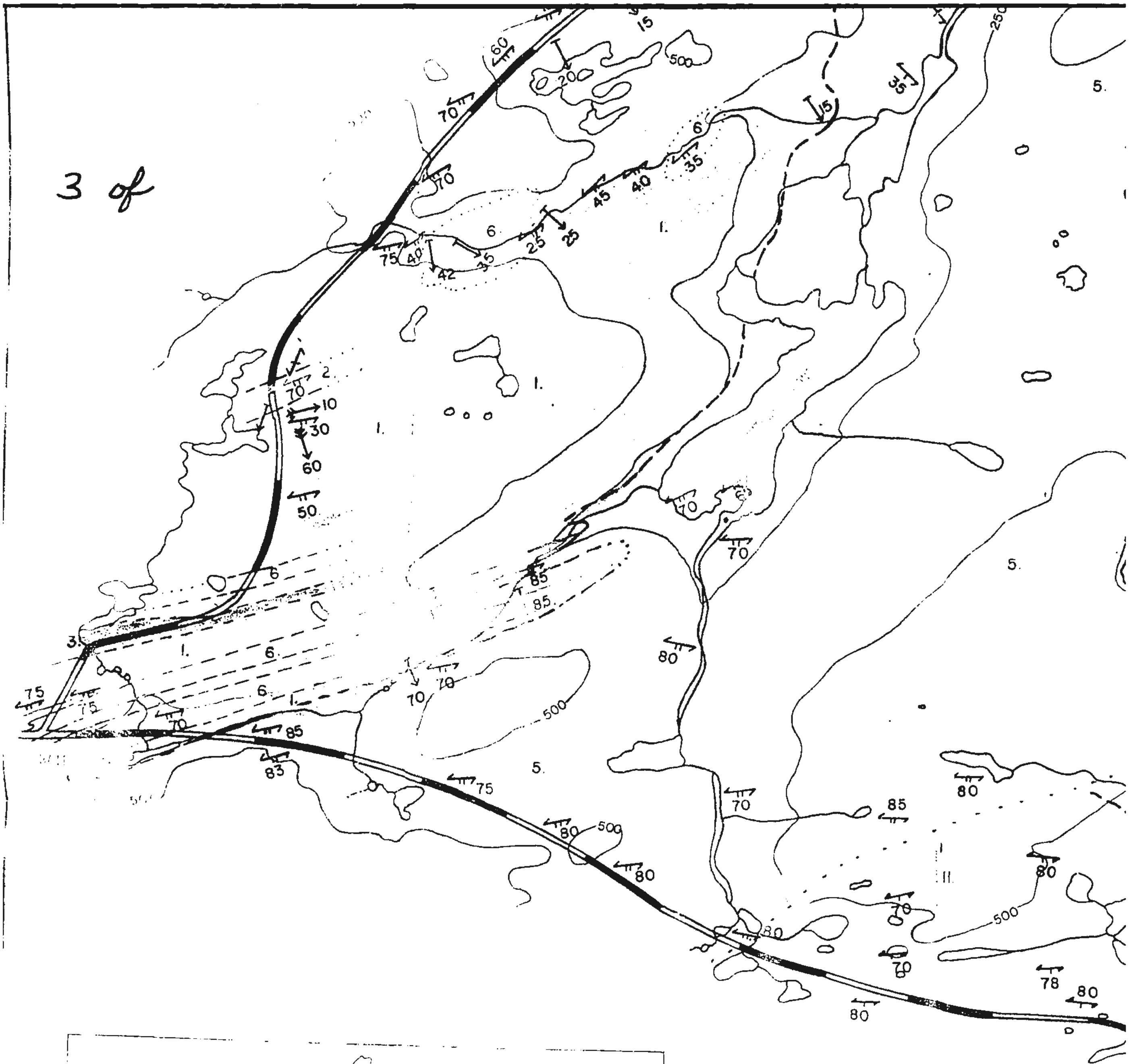


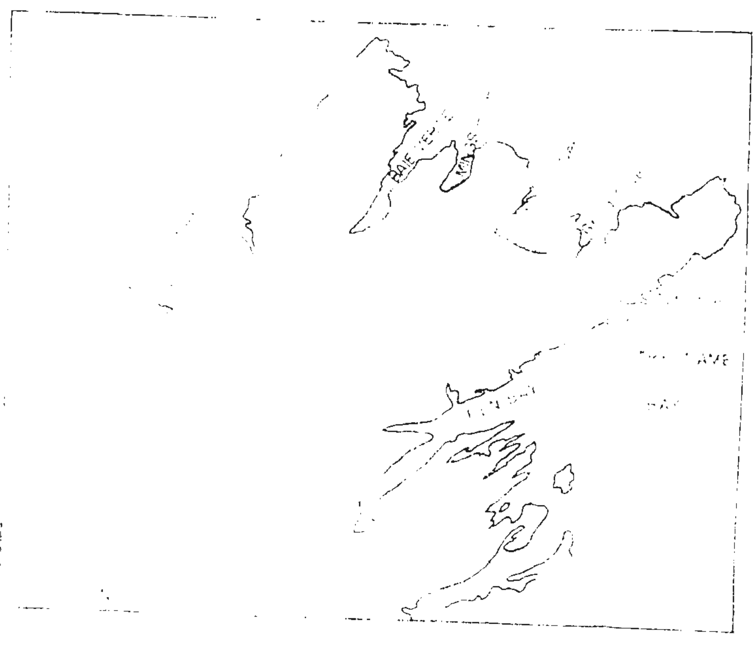
LEGEND
or OLDER
CAPE ST. JOHN GROUP
PALEOZOIC
MINOR BASIC
7. Biotite
CAPE BRULE PORPHYRY
PACQUET HARBOUR GROUP
Pelee Point
Cape Brule
Unsubdivided
3&4


Southwest Brook
250
500
750



LEGEND
or OLDER
CAPE ST. JOHN GROUP
PALEOZOIC
MIDDLE ORDOVICIAN
MINOR BASIC
7. Biotite -
4a Meta - agglomerate
N
Unsubdivided
3 & 4

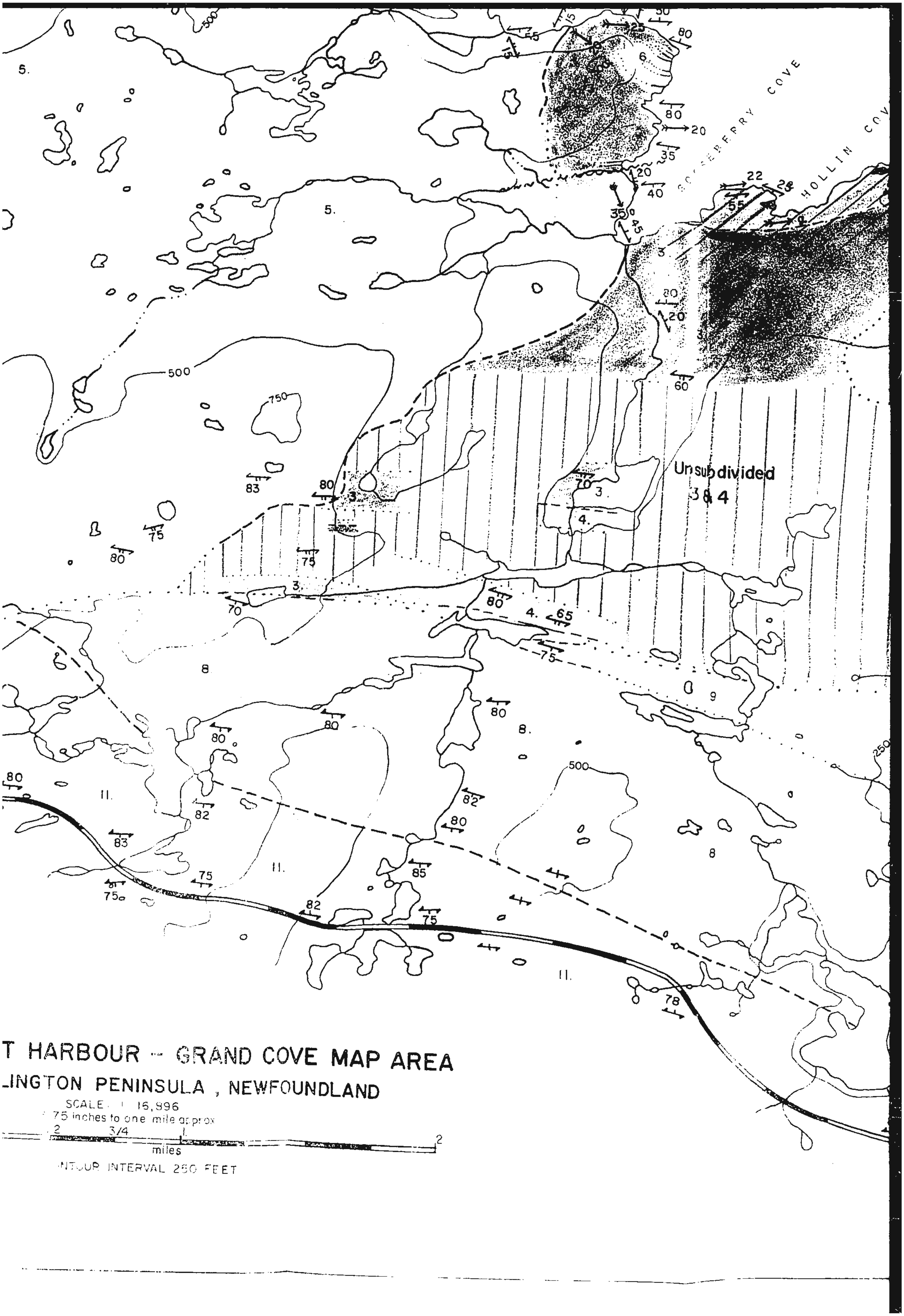


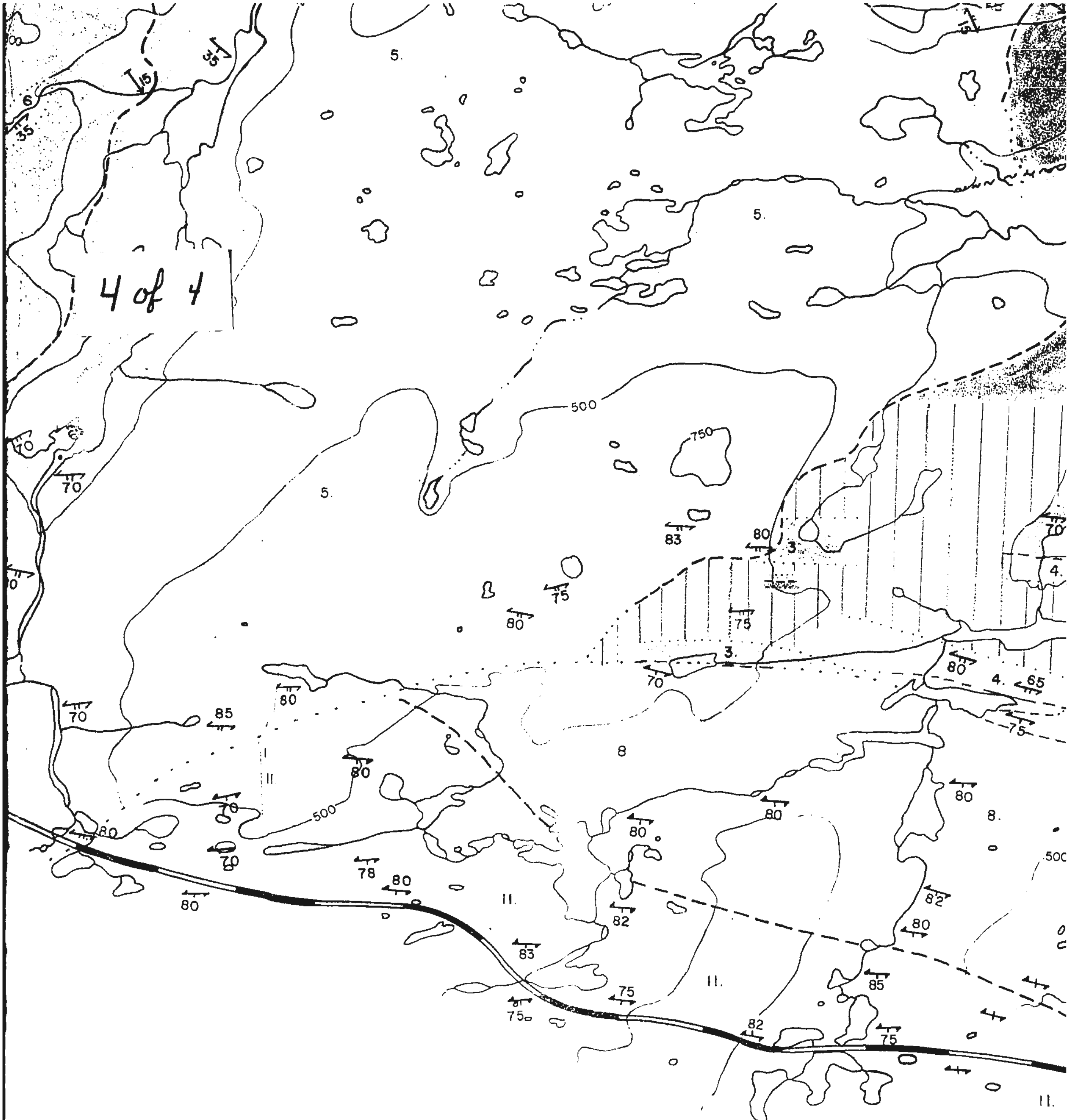


PACQUET H.

BURLING

1/4


T HARBOUR - GRAND COVE MAP AREA
-INGTON PENINSULA , NEWFOUNDLAND
SCALE 1 : 16,896
75 inches to one mile approx
miles
-NTOUR INTERVAL 250 FEET
Unsubdivided
3 & 4
GOOSEBERRY COVE
HOLLIN COV
500
750
250



PACQUET HARBOUR – GRAND COVE MAP AREA

BURLINGTON PENINSULA , NEWFOUNDLAND

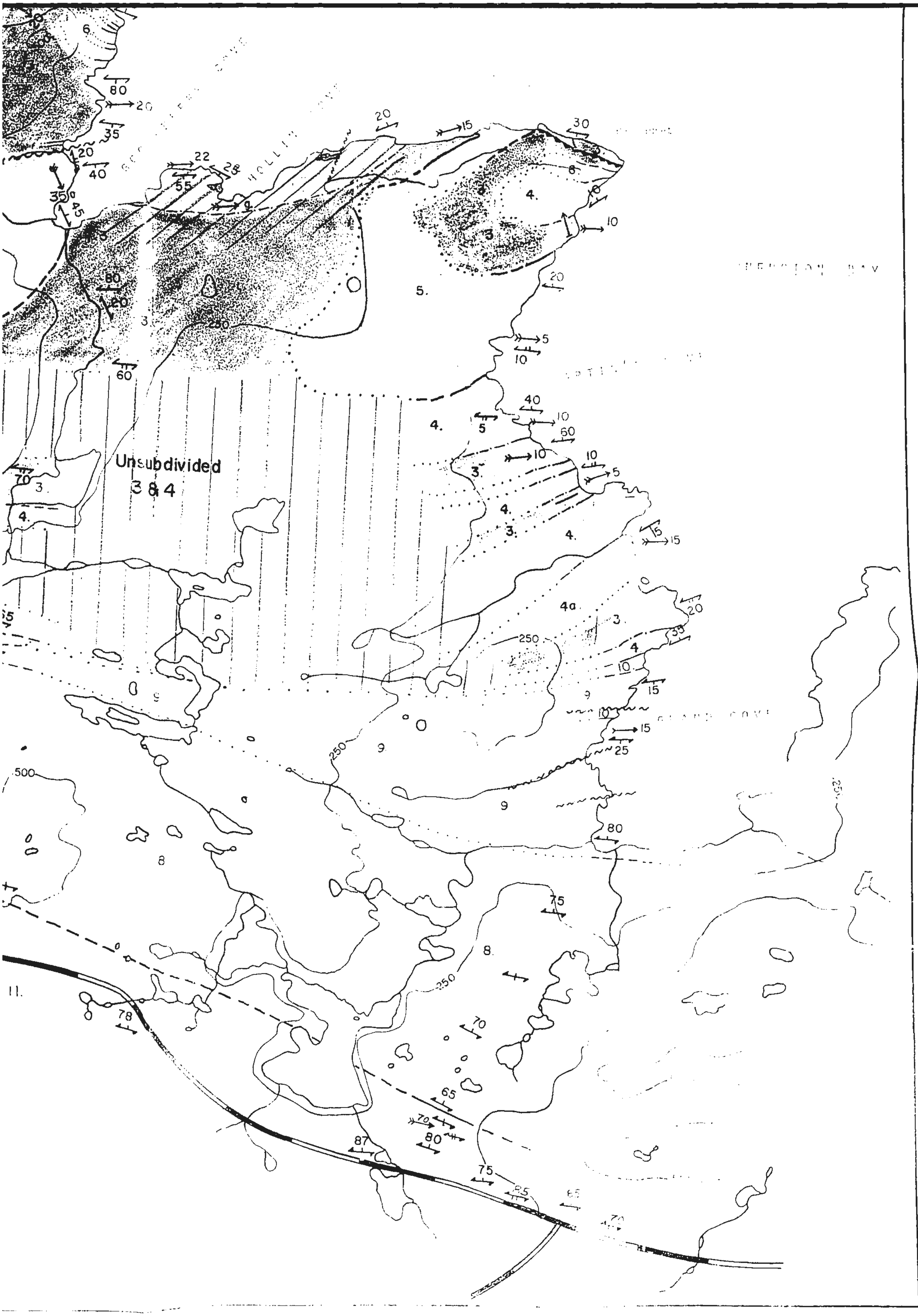
SCALE 1 16,896

75 inches to one mile approx

0 1/4 2 3/4 1 2

miles

NTOUR INTERVAL 250 FEET



Unsubdivided
3&4
4a
250
500

9/1251

75.